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MACHINERY

FOR

METALLIFEROUS MINES

*A PRACTICAL TREATISE
FOR MINING ENGINEERS, METALLURGISTS,
AND MANAGERS OF MINES*

BY
E. HENRY DAVIES, F.G.S.
MINING ENGINEER

With Upwards of Three Hundred Illustrations



LONDON
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1894

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PREFACE.

THE continued favour awarded to the mining works of my father, the late Mr. D. C. Davies, F.G.S., coupled with the recent advances and improvements in mining machinery, has created a demand for a more comprehensive and detailed description of the Machinery used in Metalliferous Mines than was permissible in the few chapters devoted to that subject in my father's work on "METALLIFEROUS MINES AND MINING," the Fifth Edition of which, revised and enlarged by myself, has recently been published.

The present work, therefore, is designed as a companion volume to the former, and is devoted exclusively to the description of the various machines in daily successful use in mining, both for the extraction and transport of the ore, and for its concentration and preparation for the market. It does not deal with the occurrence of mineral lodes, nor does it attempt to exhaust the list of the numberless new processes and new patents which the fertile brains of inventors are almost daily bringing before the public, only too often to attract a brief attention and never to come into practical use.

My endeavour has been to lay before my readers such a review of practical mining machinery as will enable them to appreciate for themselves the merits of the various machines; and while I have drawn largely upon my own experience, I have taken pains to supplement this, where necessary, by availing myself of the best sources of information. In particular, I must thank my friend, Mr. Philip Argall, M.E., of Denver, Colorado, U.S.A., to whom the chapters on Pumping Machinery are largely due; and I have also to express my obligations to the various authors to whose works reference is made, as well as to Messrs. Fraser and Chalmers and other makers of machinery for their assistance.

206, GRESHAM HOUSE, LONDON, E.C.

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MACHINERY

FOR

METALLIFEROUS MINES.

CHAPTER I.

WATER AS A MOTIVE POWER.

The Overshot Wheel—Construction—Sizes and Power—The Undershot Wheel—The Poncelet Wheel—Description—Turbines—The Fromont—Details of Construction—The Victor Turbine—Details—Power Tests—Erection—The Pelton Waterwheel—Description—Standard Dimensions—Reversible and Hoisting Wheels—Governing Arrangement—Use in Electric Installations—Price and Power—Directions for Erection—Memoranda relative to Water—The Measurement of Water—Theoretical Power obtainable—Calculation of Power—Miner's Inch Measurement.

WATERWHEELS.—The oldest known form of utilising water as a motive power is by means of a waterwheel.

Waterwheels may be divided into two general classes, overshot and undershot.

In the overshot wheel the water is applied at or near the summit, and flowing into the buckets acts by its weight alone in turning the wheel. All impulse should be avoided, and the water must flow with the same velocity as the circumference of the wheel, or just so much in excess as will prevent the buckets from striking the water as they present themselves to be filled.

In the undershot wheel the impulse of the water striking the floats drives the wheel, but the effect produced is only about half of that of the overshot wheel.

Overshot Waterwheels.—The overshot wheel is made of all diameters up to and sometimes exceeding 50 ft. ; but when such a head of water is available, it is advisable to use a turbine or Pelton wheel, which is much less cumbrous and more manageable than a waterwheel.

The water course may still strike the wheel either at the summit or at a point 45 degrees from the perpendicular, in which case the wheel is termed "high breast." In the best constructed wheels

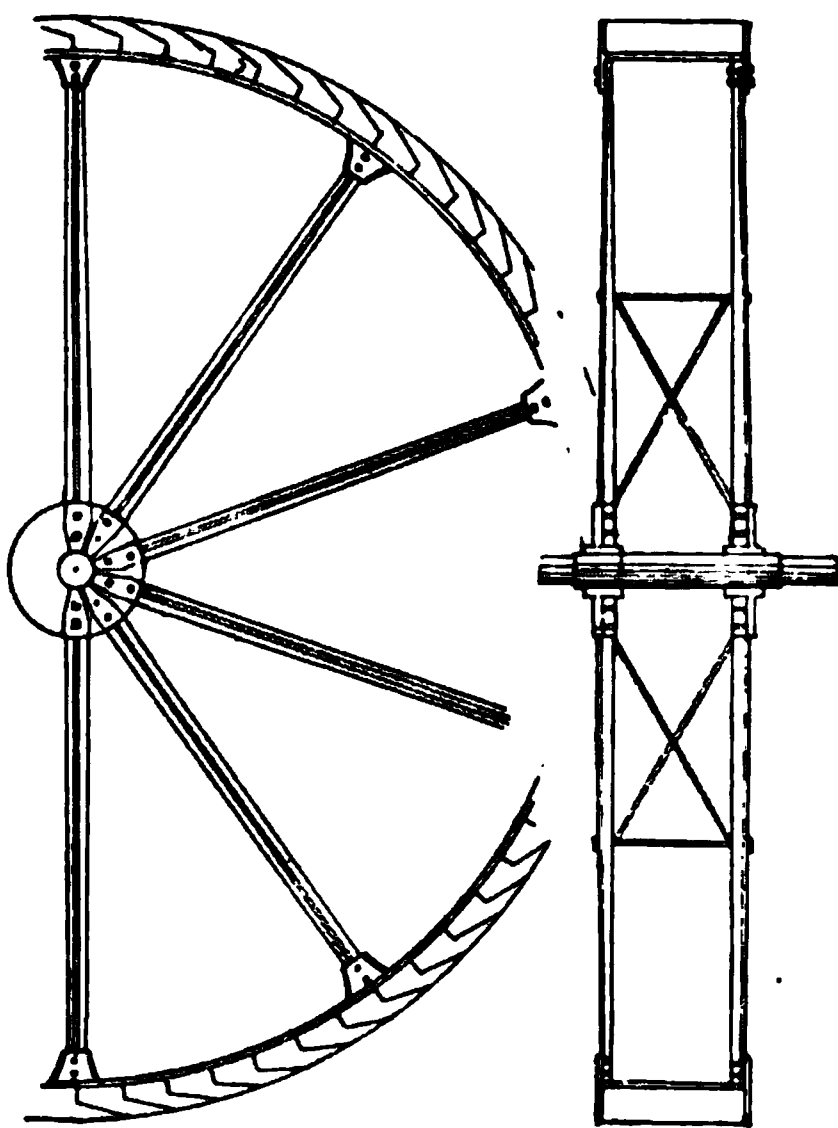


FIG. 1.—OVERSHOT WATERWHEEL.

the water is laid on in a thin sheet of no greater depth than will give it a somewhat greater velocity than that of the wheel, the difference being just sufficient to pour into the succeeding buckets the proper supply of water. The buckets should be so capacious that they need not be full when the wheel carries its maximum load, in order that no water may be wasted, and that they may retain the water in them to the last moment that its weight on the wheel is effective, and yet empty themselves as soon as it

ceases to be so. The sheet of water should not be so broad as the wheel, so as to allow a space of about 2 in. at each side for the escape of the air from the buckets ; and the velocity of the water should be somewhat greater than that of the circumference of the wheel, varying from $3\frac{1}{2}$ ft. per second for a 50-ft. wheel, up to 5 ft. per second for a 30-ft. wheel, and 7 ft. per second for a 5-ft. wheel.

The usual construction of the wheel is shown in fig. 1. The arms, which may be of iron or wood, are bolted to two cast-iron

plates fitted upon the axle. The buckets, which are made either of wood or iron, of the shape shown in fig. 2, are bolted between two shrouding plates, and are sometimes made on the ventilating system, as illustrated in fig. 3, which allows the air to make way for the ingress of the water.

Owing to the slow motion of the wheel, it may be connected direct to the axle of the roller crushers or stamps. For other purposes it is most convenient to multiply the speed by means of a spur-wheel attached to the arms near the periphery which drives a pinion at about ten times the number of revolutions of the

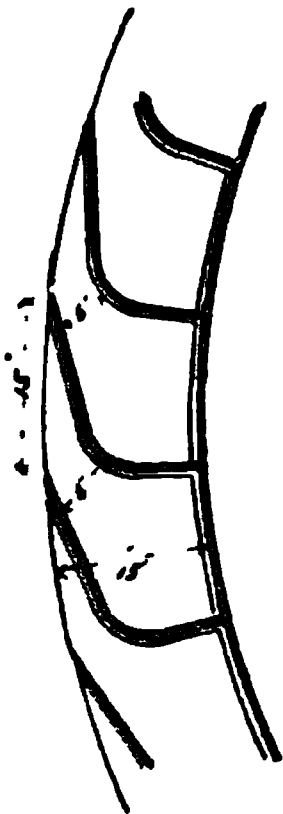


FIG. 2.—CONSTRUCTION OF BUCKETS.



FIG. 3.—VENTILATING BUCKETS.

wheel itself. By this arrangement the weight of the water is brought to bear at once on the pinion teeth, and the axle becomes as it were merely a pivot on which the wheel turns, thus allowing the arms and axle to be of considerably lighter construction. In other cases, the axle of the wheel is prolonged, and carries a spur-wheel which gears into a pinion on the inside of the mill.

In ordering a waterwheel of this class full details as to the quantity of water available, the total height of the fall from the level of the supply trough to the level of the tail-race, the actual horse-power required, and the nature of the machinery to be driven, together with a plan and section of the ground, should be furnished.

The following is a list of some of the standard sizes of overshot waterwheels, together with their horse-power and the quantity of water used :—

No.	H. P.	Head.		Diameter of Wheel.	Width of Wheel.		No. of Revolutions of Wheel.	Cubic Feet of Water per Minute.
		ft.	in.	ft.	ft.	in.		
1	6	8	6	8	4	0	18·3	640
2	6	11	0	10	3	0	12·3	455
3	6	13	0	12	2	9	10·5	390
4	10	11	0	10	4	6	12·3	800
5	10	16	0	15	3	6	7·9	530
6	10	21	6	20	2	6	5·5	375
7	15	16	0	15	4	6	7·9	775
8	15	21	6	20	3	6	5·5	590
9	15	26	9	25	3	0	4·4	500
10	20	21	6	20	4	6	5·5	750
11	20	26	9	25	3	9	4·4	550
12	20	31	9	30	3	0	3·1	520
13	25	26	9	25	4	6	4·4	775
14	25	31	9	30	3	9	3·1	640
15	30	26	9	25	5	0	4·4	940
16	30	31	9	30	4	3	3·1	760
17	35	26	9	25	5	9	4·6	1130
18	35	31	9	30	5	0	3·1	920
19	40	26	9	25	6	3	3·1	1250
20	40	31	9	30	5	6	3·1	1030

Undershot Waterwheels.—The most effective form of undershot waterwheel is that known as the Poncelet, which will develop 60 per cent. of the energy of the water, in comparison with the 30 per cent. obtained from the ordinary form.

This type of wheel is especially suited for falls of under 8 ft., where the quantity of water is large, as by this mode of working the wheel from below it is not subjected to a load of water, but receives it as it were under pressure.* This wheel can consequently be made very light, although of great power, with arms of wrought iron, like the paddle-wheels of a steamer; and as it can be driven at a greater rate than the breast-wheel, a larger quantity of water may be brought to bear upon a narrower wheel.

* "Rudimentary Treatise on the Power of Water," by J. Glynn, F.R.S. Weale's Series. Crosby Lockwood and Son.

It is fitted with curved buckets, deeper than those of a breast-wheel, and without backs or roll boards, so that within the rim of the wheel they are altogether open, and as the air can offer no impediment to the water's entrance or exit, the buckets are more numerous and their mouths narrower; one great object in this design being to make the action of the water continuous, avoiding the shock experienced in the undershot wheel; the water enters them nearly at the lowest point of the wheel, and at a tangent to it, issuing from beneath a curved sluice, which is opened by being drawn upwards by racks and pinions, as shown in fig. 4.

This sluice is nearly in contact with the wheel, so that the

FIG. 4.—PONCELET'S UNDERSHOT WATERWHEEL.

broad stream of water acts directly upon the buckets with all the pressure due to the head; and as they present themselves in rapid succession, this pressure is almost constant. The sluice is placed in an inclined position, leaning as it were against the water, and is held down by radius bars extending from the back of it to the masonry below; these bars serve not only to retain the sluice in its proper place, but to guide it as it opens or shuts down upon the sill.

A wheel on this system 16 ft. 8 in. diameter, and 30 ft. wide, driven by a fall of water 6 ft. 6 in. high, yielding 120,000 cubic feet per minute, developed 180 horse-power, when the circumference moved at the rate of 11 ft. to 12 ft per second. An

ordinary breast-wheel would have to be 90 ft. wide in order to give the same power under the same conditions, so that the Poncelet system is generally acknowledged to be the best for undershot wheels.

TURBINES.—The use of waterwheels for mining purposes is being gradually superseded by that of turbines, and these latter are usually adopted for milling work in preference to the old-fashioned wheel.

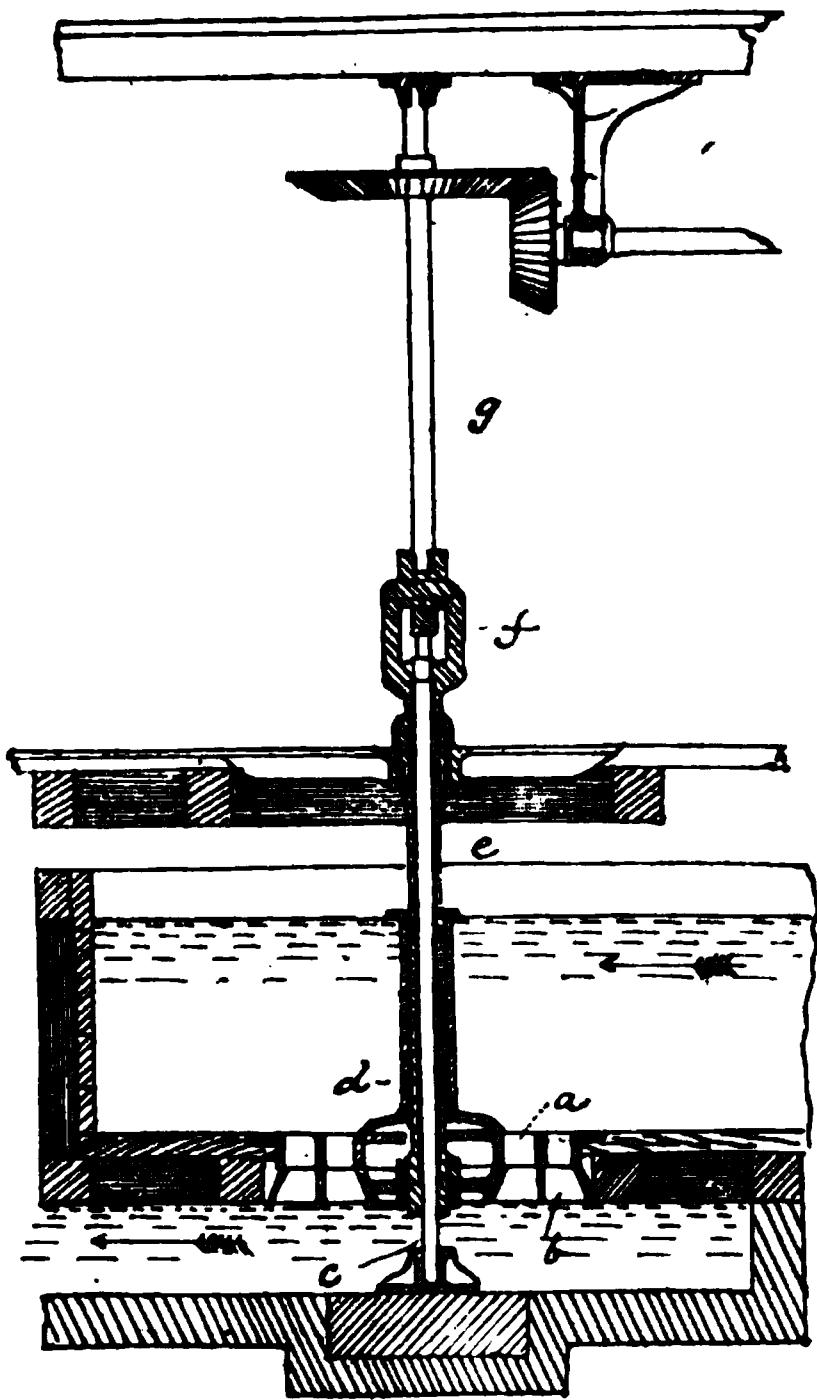


FIG. 5.—THE FROMONT TURBINE.

(fig. 6). The upper one, *a*, is fixed, and is provided with a strong flange, by means of which it is secured to the bottom of a cistern or tank, and beneath this is the revolving wheel, *b*, keyed on to a vertical sleeve, slipped over the shaft, *c*, shown also in the sectional elevation of the complete mill (fig. 5).

The fixed wheel, *a*, was 8 ft. in diameter, and was provided

This is due not only to the higher percentage of useful effect obtained, which, if the theoretical power is put at 1.00, is equal to .70, as compared with .68 in the best constructed overshot wheel, but also to their compactness and portability and the ease with which they can be controlled.

In the south of France a very simple and effective form of turbine, connected with the name of M. Fromont, is much in use; and, as I have erected one for the purpose of driving a large lead concentrating mill, I propose first of all to describe it. The wheel consists of two parts,

with a strong cast-iron pipe, *c*, about a foot in diameter, and rising above the highest level of the flood-water.

The sleeve, *c*, to which the revolving wheel is keyed, turns in suitable bearings, and is supported on the head of the vertical shaft, *e*, as shown at *f*, in such a manner that the bearing which receives the weight and thrust of the wheel can readily be got at for oiling and adjusting.

Above this point the sleeve is coupled to the vertical shaft, *g*, at the head of which the crown wheel gears in with the pinion on the end of the main shaft of the mill.

In the fixed wheel, *a*, there were forty-two openings disposed in concentric circles; the outer circle having twenty-four and the inner circle eighteen. These openings radiated from the centre of the wheel and were formed, as shown in the section, to direct the water into the buckets of the revolving wheel below it. The shape of the buckets in both wheels is clearly shown in the section, and their arrangement in the plan (fig. 6).

FIG. 6.—HALF PLAN AND SECTION OF THE FROMONT TURBINE.

The wheel was controlled by means of sluices in the canal leading to the turbine chamber, but can be arranged so as to govern its own speed, which was 80 revolutions per minute.

The head of water at the summer level of the river was 1 m. 40, say 4 ft. 6 in., and the quantity was unlimited. The nominal horse-power was 50, but the actual was nearer 80. During flood times the head was diminished and sometimes completely

annulled, rendering the turbine useless. For nine months in the year, however, the wheel worked most satisfactorily, and never caused any trouble. The crown wheel was fitted with wooden teeth, and these had occasionally to be renewed.

Wheels of this type are largely used in France for driving flour, spinning, rolling, and lead-dressing mills, and their extreme simplicity and great efficiency have made them very popular.

The Victor Turbine.—The turbine on the Fromont principle, which I have just described, works best under low heads and with a large volume of water. For heads of from 20 to 80 ft. a different type of machine is to be preferred, and for very high heads the Pelton wheel is best adapted.

There are numerous makes of turbine manufactured and suitable for medium heads, such as the Vortex, Victor, the Jonval, and the Leffel; and for heads between the medium and high, the Girard; but we will content ourselves with describing the Victor, which embodies the best principles, and under proper conditions will develop as much as 80 per cent. of the full power of the water.

Fig. 7 is an illustration of the Victor wheel and case complete. The machine may be said to consist of three parts—viz., the outer case and cylinder, the register gate, and the wheel.

The outer case is shown in fig. 8, with the bridge-tree and

FIG. 7.—THE VICTOR TURBINE.

FIG. 8.—VICTOR TURBINE OUTER CASE.

wood step which support the wheel in position. It is formed of one casting, bored out true to receive the register gate, which revolves within it to a certain extent. On the outside a flange is cast and turned up true, at right angles to the wheel shaft. This flange rests on, and is secured to, the floor of the turbine chamber.

The register gate (fig. 9) is cast in one piece, with fixed water-ways. It is bored out to receive the wheel, and turned true to fit inside the

FIG. 9.—REGISTER GATE OF THE VICTOR TURBINE.

outer case, within which it can be turned by means of a short ratchet and pinion. This movement of the register gate regulates the amount of water supplied to the wheel and secures an equal and uniform delivery on all its parts without changing the direction

FIG. 10.—TOP OF TURBINE.

of the current or checking the velocity of the water admitted to the wheel. The pinion which moves the register-gate is worked by hand, and is also under the control of a governor, by means of which the speed of the wheel is kept constant under varying loads.

The wheel case is covered with the top shown in fig. 10, to which the pedestal which carries the wheel-shaft is attached. The shaft of the governing pinion also passes through this cover.

The wheel (fig. 11) fits inside

FIG. 11.—THE VICTOR TURBINE WHEEL.

the cylinder and register gate and its construction is shown in the drawing. It receives the water upon the outside and discharges it downward and outwards, the lines of the discharge occupying the entire diameter of the lower portion of the wheel, excepting the space filled by the lower end of the shaft.

The whole turbine is of a simple, but powerful and effective, construction, and the smallness of its size is of great advantage for shipping and transport purposes ; while the following record of official tests gives valuable information as to its efficiency, power, and the quantity of water required :—

POWER TESTS OF THE VICTOR TURBINE.

	Head in Feet.	Revolutions per Minute.	Horse- Power.	Cubic Feet of Water.	Percentage Useful Effect.
15-in. Victor ... {	18·34	323·0	29·36	973·75	·8705
	18·10	321·5	29·22	970·39	·8808
15-in. Victor ... {	18·06	368·0	30·17	990·19	·8932
	18·08	355·0	30·12	996·83	·8849
15-in. Victor ... {	18·01	345·0	27·00	923·40	·8595
	17·98	342·0	26·76	920·40	·8564
	17·97	348·0	26·71	920·0	·8551
17½-in. Victor ... {	18·02	280·0	35·51	1164·60	·8960
	17·96	292·0	36·35	1197·0	·8950
	17·96	284·6	35·84	1202·4	·8790
20-in. Victor ... {	18·22	286·0	48·75	1660·17	·8532
	18·23	275·0	48·75	1660·17	·8528
	18·21	269·5	49·00	1671·57	·8522
25-in. Victor ... {	17·79	205·5	67·72	2362·72	·8530
	17·96	209·0	68·62	2356·54	·8584
	17·80	212·5	67·61	2356·0	·8533
30-in. Victor ... {	11·65	144·5	52·54	2751·87	·8676
	11·66	147·5	51·96	2755·09	·8564
	11·70	142·0	52·02	2738·0	·8614
35-in. Victor ... {	17·13	147·5	134·09	4994·0	·8289
	17·10	150·0	134·09	4981·0	·8334
35-in. Victor ... {	17·31	151·7	135·68	4895·0	·8489
	17·29	160·0	133·19	4806·0	·8497
	17·32	147·0	136·08	4805·0	·8491

The turbine can be fixed in the bottom of a turbine-chamber, formed either of a pit lined with brickwork, or of a wrought-iron

flume, with an outlet below the wheel for the tail-race ; in which case the shaft is vertical and drives the main horizontal shafting of the mill through bevel gearing ; or the wheel can be arranged horizontally, as shown in fig. 12.

In this latter case it is usual to employ a pair of wheels in order that the one may counterbalance the other, and the end thrust on the shaft is thus annulled. A pulley is provided at each end, from which belts convey the power to the main shafting. The governing arrangement is shown on the top, as well as the hand-wheel for starting and stopping the mill. The water is brought under pressure to the turbine through wrought-iron pipes, and

FIG. 12.—VICTOR TURBINE (HORIZONTAL).

escapes through the curved pipes shown at each side into the tail-race below. Single horizontal turbines can also be obtained for places where the supply of water is small, but the double horizontal is to be preferred for the reason mentioned.

There is no special difficulty in the erection of this turbine ; the great point is to utilise the full available head and to provide ample space for the discharge of the spent water. The machine must be fixed perfectly level, and great care taken to have all the shafting and bearings in perfect line, for a little unnecessary friction in the different bearings causes a heavy loss of power and an increase in the wear and tear.

The velocity of the water as it arrives at the turbine should not

exceed $1\frac{1}{2}$ ft. per second, and the head-race should be free from all sharp bends and other obstructions to the flow of the water. A grating should be fixed so as to prevent the water from carrying sticks and other rubbish down into the passages of the wheel. The tail-race should be larger, if possible, than the head-race, and should be so constructed that when the wheel is not at work there shall be 2 ft. of dead water in the bottom of the race.

THE PELTON WATERWHEEL.—The great advances which have been made of recent years in electricity, and its conversion into motive power, have turned the attention of engineers to the perfection of the machinery by which the “countless wealth, which is being squandered in all the torrents and watercourses of the world,” can best be utilised and enslaved by means of waterwheels and turbines to the service of man.

The Pelton waterwheel, which is one of the comparatively recent inventions, seems to have been born amongst the foothills and mountain ranges of California, where, owing to the high head and often small quantity of water, the ordinary form of turbine or waterwheel was of but limited service.

The Pelton is what may be termed a tangential reaction wheel, the power of which is derived primarily from the pressure afforded by a head of water, supplied by a line of pipe discharged upon it through a small nozzle, the size of which is proportioned to the amount of water available and the head and power required. Its general form will be seen by reference to fig. 13, which shows the wheel and its buckets, the nozzle and regulating valve or gate, and the pulley, from which the power is conveyed to other machinery. The wheel itself is in practice hooded in with boards or sheet iron to prevent the splash. The manner of utilising the pressure of the water in the pipes is the distinguishing feature, and the secret of the means by which as much as 88 per cent. of the theoretical energy of the water can be realised.

As will be seen from the drawing, the buckets on the circumference of the wheel are of a peculiar shape, with a wedge in the centre, which divides the stream in such a way as to develop its full force ; while in passing out it sweeps against the curved sides with a reactionary influence, giving it the effect of a prolonged impact. It is also by this means deflected from the course of the

wheel, so as to offer no resistance to its motion. That the power of the water is fully exhausted would appear from the fact that it falls from the buckets practically inert, no water being carried over; nothing but a mist above and a stream below to indicate the force which has been liberated.

The Pelton is essentially a high-pressure wheel, but it is also adapted to moderately low heads; although, when these latter are only from 10 ft. to 20 ft., it would appear that the ordinary

FIG. 13.—THE PELTON WATERWHEEL.

turbine can fairly compete with it, so that it is not recommended for heads of less than 25 ft.

As regards the extreme pressure consequent upon high heads, there is no practical limit to the head under which it can be operated; as, for instance, at the collar shaft on the Comstock, where a Pelton is at work under a head of 1680 ft., equal to a pressure of 722 lb. per square inch, and realises an average efficiency of 88 per cent. It has been running under these conditions for over three years, and the only repairs needed have been the replacing of a few buckets.

The dimensions of a 6-ft. standard wheel will be found in fig. 14; and wheels are made in all sizes downwards, from this

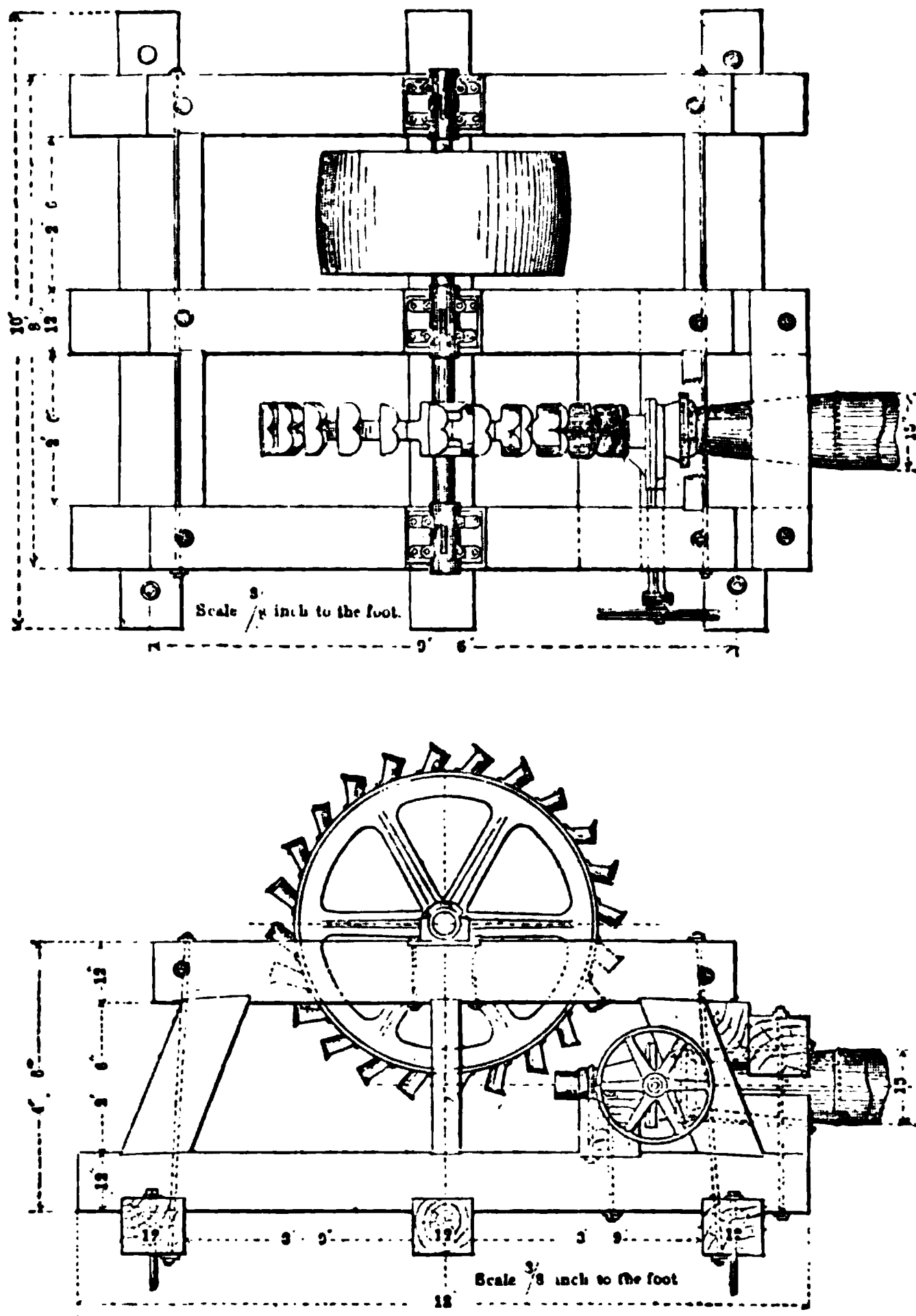


FIG. 14.—6-FT. STANDARD PELTON WATERWHEEL.

to a 4-in. wheel, which can be used for driving a sewing machine or other light work.

The power of a Pelton wheel does not depend upon its diameter, but upon the head and amount of water applied to it. Where a very considerable power is wanted under a comparatively low head, a larger wheel is necessary, in order to admit of buckets of sufficient size to cope with a larger stream of water. Wheels of greater dimensions are also desirable in many cases with reference to reducing the speed, when the smaller will furnish all the power needed.

The velocity of the wheel being determined by the head, the

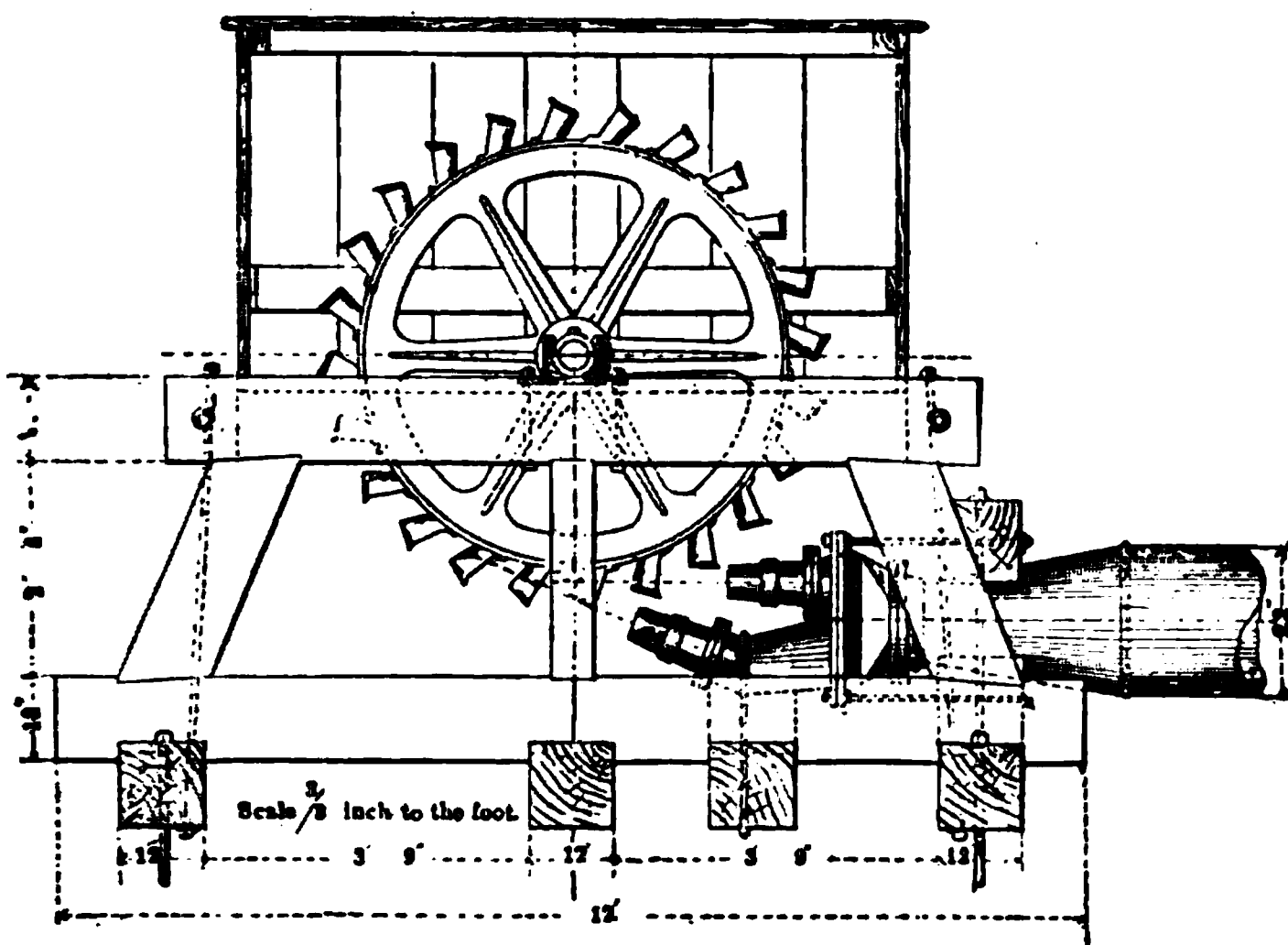


FIG. 15.—6-FT. DOUBLE NOZZLE PELTON WATERWHEEL.

diameter can then be made to conform to the speed required, and the buckets and nozzle delivery proportioned to the amount of water available and power wanted.

When the head of water is low, but the quantity considerable, a wheel with two or more nozzles, as shown in fig. 15, can be employed. Where these are used, one or more nozzles can be stopped off when the additional power they afford is not wanted, or when for any reason the water supply partly fails. Wheels with several nozzles are of great use for hoisting purposes, as in

double winding shafts or inclines, where this arrangement admits of using all the streams when starting the load, and shutting off one or more when it rises; affording thus economy of water, and perfect control of the cages or trucks.

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FIG. 16.—THE PELTON WATERWHEEL. THREE NOZZLE REVERSIBLE. PLAN.

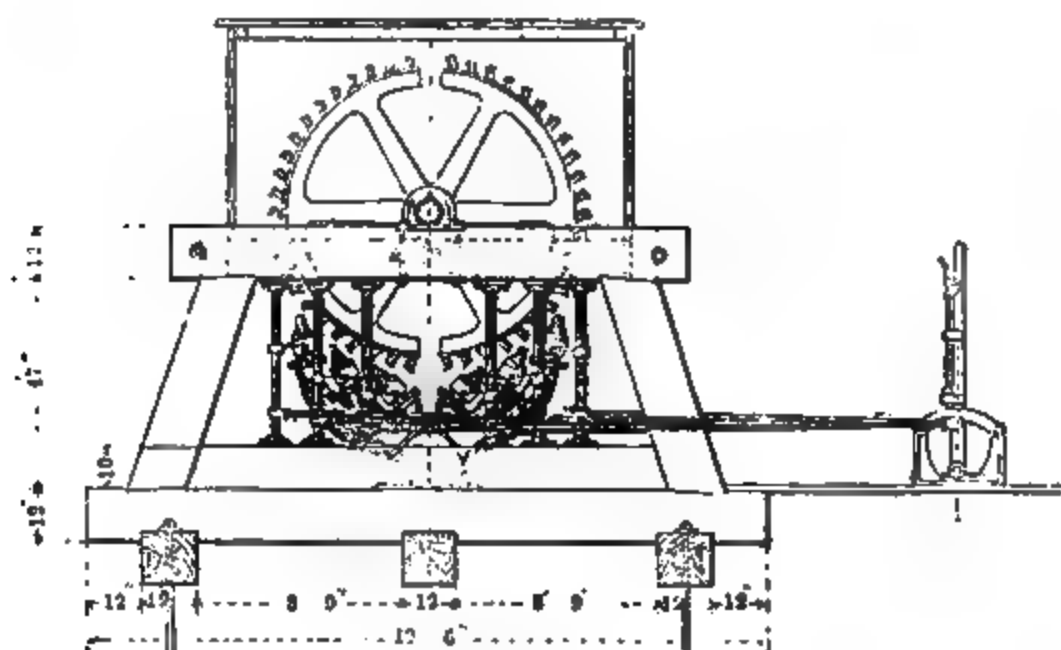


FIG. 17.—THE PELTON WATERWHEEL. THREE NOZZLE REVERSIBLE. SECTION.

A good arrangement of two reversible hoist wheels keyed on one shaft is shown in figs. 16 and 17. Three streams are applied

THE PELTON WATERWHEEL WITH HOISTING GEAR. 17

to each wheel by a system of triple nozzles, each furnished with independent stop-valves, which are operated by hand levers placed in a convenient position, and connected by rods and

or

FIG. 18.—PLAN OF PELTON WHEEL AND HOISTING GEAR.

FIG. 19.—SINGLE DRUM GEARED HOIST WITH PELTON WHEEL. ELEVATION.

cranks to the valve spindles. The motion can thus be controlled or reversed at pleasure, and adapted to double winding and hoisting purposes.

For single hoisting purposes, where the load can be lowered by

a brake, the Pelton wheel may be utilised as indicated in figs. 18 and 19, where a single nozzle wheel is connected to a winding drum by means of spur gearing.

The drum can be disconnected by the clutch, and controlled by the brake when lowering; while the quantity of water supplied to the wheel is regulated by the hand lever and water gate. The driver has thus complete control over the machine, and for winding with a single rope, either from a pit or up an incline, where the weight of the load is sufficient to effect the lowering operation, this arrangement will be found particularly useful.

FIG. 20.—THE PELTON WATERWHEEL WITH REGULATING ATTACHMENT.

When it is desired to maintain an even speed with a varying load, and great regularity in the number of revolutions per minute, as in mills, where various machines are being constantly thrown in and out of gear, or in electric installations, a deflecting nozzle is applied to the wheel, as in fig. 20. This consists of a nozzle of from 3 ft. to 5 ft. long, attached to the main piping and valve by means of a ball joint, operated by means of a lever and rocking shaft.

With these attachments the whole or any part of the stream can be thrown on or off the wheel instantly by hand, or gradually by means of a governor, thus affording such variations of speed

and power as may be desired to accommodate any change in the load.

With all the wheels described a set of three nozzle tips is furnished, to admit of the wheel being used to its full capacity when the largest is used; while the other ones are employed, when it is wished, to economise the water.

The Pelton wheel should be fixed at the lowest convenient spot

FIG. 21.—PELTON MOTOR WITH DYNAMO CONNECTION.

in the mill. The foundations required are very simple. In some cases the weight of the framework is sufficient, but as a general rule it would be better to bolt it down to a block of concrete or stonework, or to the rock.

The wheel is connected to the main line of shafting by means of a belt; but for air compressing, when the wheel is not less than 8 ft. in diameter, it may be connected direct to the compressor shaft.

For electric installations the Pelton wheel seems to be well

adapted, and is being used for this purpose in various parts of the world. For small installations the motor can be connected direct to the shaft of the dynamo, as in fig. 21, where a No. 2 Pelton motor, 12 in. in diameter, is driving a Thompson-Houston dynamo, having a capacity of 65 incandescent lights of 16 candle-power each. The motor makes 1350 revolutions per minute, under a head of 325 ft., equal to a pressure of 140 lb. per square inch. It has been applied as the motive power of many large installations, both for lighting and for the generation of electricity for transmission to distant works, and reconversion there into power, as described in Chapter XXVII.

The following table shows the power of these wheels under different heads and varying diameters, and also the price and weight :—

PRICES, POWER AND WEIGHT OF PELTON WATER WHEELS.
Standard Sizes.

Head in Feet.	3-ft. Wheel.		4-ft. Wheel.		5-ft. Wheel.		6-ft. Wheel.	
	H. P.	Price.	H. P.	Price.	H. P.	Price.	H. P.	Price.
20	1.50	£44	2.64	£57	4.18	£70	6.00	£80
50	5.98	44	10.60	57	16.63	70	23.93	80
80	12.04	46	21.44	59	33.54	74	48.16	85
100	16.84	48	29.93	60	46.85	76	67.36	90
150	31.01	50	55.08	64	86.22	80	124.04	95
200	47.75	53	84.81	70	132.70	85	191.00	100
250	66.74	56	118.54	80	185.47	90	266.96	111
300	87.73	60	155.83	85	243.82	97	350.94	125
350	110.56	64	196.38	92	307.25	110	442.27	140
400	135.08	68	239.94	100	375.40	125	540.35	160
450	161.19	72	286.31	108	447.95	140	644.78	180
500	188.80	78	335.34	120	524.66	155	755.20	200
550	223.76	85	397.43	135	621.82		895.04	
600	248.16	90	440.77	150	689.63		992.65	
700	312.73	100	555.46		869.06		1250.92	
800	382.09		678.66		1061.81		1528.36	
900	455.94		809.82		1267.02		1823.76	
1000	534.01		948.48		1483.97		2136.04	
	Weight, 700 to 1000 lb.		Weight, 1000 to 1700 lb.		Weight, 1400 to 2100 lb.		Weight, 2100 to 3000 lb.	

DIRECTIONS FOR SETTING THE PELTON WHEEL.

Timber Framework.—Make frame as shown in fig. 13, subject to such variations as may be necessary to suit special conditions. See that the framework when in position is level, and the wheel shaft in line with its bearings. Tramp well the earth and rock about the mud-sills until it has a secure foundation, and if the wheel is to develop large power, the mud-sills should be bolted to a stone or wood foundation, set deep in the ground, or on concrete.

Putting on the Buckets.—The wheel should first be put in place on the shaft before putting on the buckets. The buckets after being properly fitted in the shop, are numbered and taken off for shipment, and when put on should be fitted to a corresponding number on the rim of the wheel, care being taken in turning up the nuts on bolts. Both head and nut should be firmly seated, but not so tight as to bring an undue strain on the bolts, rendering them liable to give way.

Housing-in the Wheel.—The cover or top housing should extend one inch below the bottom of the boxes on the inside of the timbers, resting on cleats, and left loose so that it can be taken off. For the lower housing, put cleats on the under side of upper timbers and legs and on top of sills 2 in. from the outer edge, to allow of boarding double thickness, and making this come flush with the outside of timbers. The ends are boarded on the outside of the legs. A door should be put in opposite the nozzle of the wheel large enough for convenient access to same. The floor under the wheel should be made of 1 in. boards, doubled to prevent leakage. The lower part of the casing for the smaller wheels should have about 12 in. clearance on each side of the buckets, and the larger sizes say 22 in., to admit of a free discharge, and the tail-race should have sufficient fall to prevent water backing up on the wheel.

Anchoring Gate and Nozzle.—The gate and standing nozzle should be firmly anchored and braced, especially when working under high heads, so that the force of the water may not move the nozzle or wheel frame from their position. Reliance should not be made in such case altogether upon the wheel frame for securing the nozzle and gate against the pressure of the water, but they should be anchored by rods with turn buckles to masonry or heavy timbers sunk in the ground up stream from the wheel.

Setting the Nozzle.—A template made of Russian iron is sent with every wheel for the purpose of giving the proper setting to the nozzle. The lower edge of the template should rest on the top of the standing nozzle, while the upper curve should conform to the periphery of the buckets. When this adjustment is made, screw the tip into the outer end of the nozzle.

When properly adjusted, the stream will be thrown parallel with the wheel and be divided in its centre by the splitter in the centre of the buckets.

Great care should be exercised in setting the nozzle, as the working results depend largely upon the right application of the stream to the wheel.

Gate, Nozzle, and Tips.—The gate is set behind and in close proximity to the wheel. The nozzle is attached to and forms a part of the gate. The outlet of the nozzle has a thread into which the tips are screwed, which discharge the water on to the wheel. These are short and conical in form, large enough at the butt to make connection with the nozzle, while the discharged end is bored to suit any required delivery, the outlet in the various sizes ranging from $\frac{1}{4}$ in. up to 6 or 8 in. in diameter.

Three tips are sent with each wheel, the largest for the maximum power desired, and the others of reduced capacity. An additional number are furnished where a wide range of power is wanted. Full information as to power should be given for the purpose of making proper adaptation in this regard. A change of tips is but the work of a moment by the use of a wrench or spanner. In putting them on it is advised to use oil to prevent rust, and to facilitate change.

Speed of Wheel.—The speed of the wheels is in all cases determined by the pressure, and they should be geared to run the number of revolutions given in tables under heads named, otherwise they work at a great disadvantage, and will fail to develop their full power. The tables are based upon giving the peripheral velocity of the wheel one-half the spouting velocity of the water. Should the effective head from any cause be reduced, the speed should be made to conform to such change by lagging up the driving pulleys.

It is advisable in all cases to have a gauge connected to the water gate by a small pipe.

This will indicate the running and standing pressure, and show how much head is lost by friction while discharging different quantities of water. An ordinary steam gauge will answer for this.

THE MEASUREMENT OF WATER.—When the question of the motive power of a mill is being considered, as well as that of the supply of water for the concentration process, it often becomes necessary to ascertain the quantity of water which is available ; and the following are some of the means by which they may be decided.

For small quantities of water under, say 120 gallons per minute, the simplest plan is to take a tank or barrel which would fill in from 30 secs. to 60 secs., and time the operation, and from that calculate the volume in gallons per hour or day, as may be required.

This process cannot be conveniently followed when a small stream has to be measured, and in this case the rate of flow through a known aperture is the basis of the calculation. A board is placed at right angles across the stream in such a manner as to

form a pond. A notch is cut in the board an even number of feet long, say two, and of a depth of six inches. These dimensions vary according to the size of the stream. The edges of the notch should be bevelled towards the up stream, and the lower edge of it should be at a distance of at least twice the depth of the notch above the level of the bed of the brook so as to give a clear overflow. The board is securely staked down and puddled so that the whole of the water must run over the weir formed by the notch. A few feet up stream within the pond a stake is driven down with its head exactly on a level with the edge of the notch, so that the depth of the water taken by means of a rule from the top of the stake, will be exactly the depth of the water flowing over the edge of the weir. Knowing this depth and the width of the notch we have the bases for the calculation of the quantity which can be readily found from the table on page 24.

This arrangement for measuring the volume of the current of water in a stream, may be constructed either for permanent or temporary observations, and the amount of labour spent upon its erection will depend thereon. In either case great care must be taken to make the dam watertight around the bottom and sides, and to have a clear overfall with the edge of the notch perfectly level. Instead of a stake cut off to the level of the edge of the notch, a stake with a scale of inches attached may be used instead. In this case the stake is driven as before into the bed of the stream, a yard or so above the dam, and a zero mark made upon it at the exact height of the edge of the notch. A scale of inches and fractions or decimals is started upwards from this zero, and the height of the water above the edge of the notch can thus be read at a glance.

This arrangement of a weir-dam is employed where the whole of the water is to be appropriated to the purposes of the mine and mill. When, however, it is a question of taking only a portion, and paying for that portion, often at a high figure, the plan to be preferred is that described on page 27 as miner's inch measurement, reducing the quantities, however, to cubic feet as being the standard upon which all tables of power and efficiency are based.

TABLE OF DISCHARGE FROM EACH FOOT WIDTH OF NOTCH OR SILL IN CUBE FEET PER MINUTE (Molesworth).

DECIMALS OF AN INCH.										
Depth of Water on Sill.										
Inches.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	Cubic Feet. 0.0	Cubic Feet. .162	Cubic Feet. .46	Cubic Feet. .846	Cubic Feet. 1.30	Cubic Feet. 1.823	Cubic Feet. 2.34	Cubic Feet. 3.02	Cubic Feet. 3.68	Cubic Feet. 4.4
1	5.15	5.92	6.75	7.62	8.55	9.42	10.4	11.38	12.41	13.49
2	14.57	15.65	16.79	17.97	19.16	20.34	21.58	22.87	24.1	25.44
3	26.78	28.12	29.56	30.9	32.14	33.78	35.28	36.77	38.16	39.55
4	41.2	42.74	44.29	45.78	47.48	49.13	50.73	52.53	54.07	55.62
5	57.58	59.17	60.92	62.83	64.53	66.33	68.29	70.04	71.89	73.9
6	75.70	77.56	79.46	81.42	83.38	85.23	87.24	89.35	91.26	93.26
7	95.38	97.44	99.54	101.6	103.6	105.8	107.9	109.9	112.1	114.3
8	116.5	118.6	120.9	123.1	125.4	127.6	129.8	133.0	134.4	136.7
9	139.0	141.3	143.9	146.0	148.4	150.7	153.2	155.5	157.9	160.4
10	162.8	165.3	167.7	170.2	172.7	175.2	177.7	180.2	182.8	185.3
11	187.9	190.4	193.0	195.6	198.2	200.8	203.4	206.1	208.7	211.4
12	214.1	216.7	219.4	222.1	224.8	227.5	230.3	233.0	235.8	238.5

DECIMALS OF A FOOT.										
Depth of Water on Sill.										
Feet.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	Cubic Feet. 0	Cubic Feet. 6.7	Cubic Feet. 19	Cubic Feet. 34	Cubic Feet. 53	Cubic Feet. 75	Cubic Feet. 99	Cubic Feet. 125	Cubic Feet. 153	Cubic Feet. 183
1	214	246	280	317	357	391	432	472	515	560
2	605	650	697	746	796	845	896	950	1001	1057
3	1112	1168	1228	1284	1335	1401	1465	1527	1585	1643
4	1712	1776	1840	1902	1973	2041	2107	2182	2247	2311
5	2392	2458	2531	2610	2681	2756	2838	2910	2987	3070
6	3145	3222	3302	3383	3464	3541	3625	3712	3792	3875
7	3963	4049	4132	4220	4305	4395	4483	4569	4658	4751
8	4843	4930	5022	5116	5210	5303	5397	5489	5583	5682
9	5778	5872	5970	6067	6165	6264	6364	6463	6563	6664

When the stream is too large to admit of the construction of a weir, as above described, or by Miner's inch measurement, as explained on page 27, an approximate idea of the quantity of water flowing down it may be obtained as follows :—

Measure the depth of the water at from 6 to 12 points across the stream at equal distances between. Add all the depths in feet together and divide by the number of measurements made ; this will be the average depth of the stream, which multiplied by its width will give its area or cross section. Multiply this by the velocity of the stream in feet per minute, and the result is the quantity in cubic feet per minute of the stream.

The velocity of the stream can be found by laying off 100 ft. on the bank and throwing a float into it at the middle, noting the time passing over the 100 ft. Do this a number of times and take the average. Then dividing this distance by the time gives the velocity in feet per minute at the surface. As the top of the stream flows faster than the bottom or sides,—the difference being about 8 per cent.—it is better to measure a distance of 110 ft. for float and reckon it as 100.

The power which may be obtained from a given quantity of water falling through a given height, as in overshot waterwheels, or under a given head, as in turbines or Pelton wheels, varies greatly with the efficiency of the machine which is used to convert it into motive power.

Thus putting the theoretical power due to the weight of the water and the head at 100, we have the following coefficients of efficiency for the various types of water-motor machines usually employed :—

EFFECTIVE HORSE-POWER OF DIFFERENT WATER MOTORS.

Theoretical power being	1'00
Undershot waterwheels	'35
Poncelet's undershot waterwheel	'60
Breast-wheel	'55
High breast-wheel	'60
Overshot wheel	'68
Turbine	'70
Hydraulic ram raising water	'60
Water-pressure engine	'80
Pelton waterwheel (high pressure)	'85

TABLES FOR CALCULATING THE HORSE-POWER OF WATER.

Based upon an efficiency of 85 per cent.

Miner's Inch Table.

The following table gives the horse-power of one miner's inch of water under heads from 1 up to 1100 ft. This inch equals $1\frac{1}{2}$ cubic ft. per minute.

Heads in Feet.	Horse- power.	Heads in Feet.	Horse- power.
1	·0024147	320	·772704
20	·0482294	330	·796851
30	·072441	340	·820998
40	·096588	350	·845145
50	·120735	360	·869292
60	·144882	370	·893439
70	·169029	380	·917586
80	·193176	390	·941733
90	·217323	400	·965880
100	·241470	410	·990027
110	·265617	420	1·014174
120	·289764	430	1·038321
130	·313911	440	1·062468
140	·338058	450	1·086615
150	·362205	460	1·110762
160	·386352	470	1·134909
170	·410499	480	1·159056
180	·434646	490	1·183206
190	·458793	500	1·207350
200	·482940	520	1·255644
210	·507087	540	1·303938
220	·531234	560	1·352232
230	·555381	580	1·400526
240	·579528	600	1·448820
250	·603675	650	1·569555
260	·627822	700	1·690290
270	·651969	750	1·811025
280	·676116	800	1·931760
290	·700263	900	2·173230
300	·724410	1000	2·414700
310	·748557	1100	2·656170

Cubic Feet Table.

The following table gives the horse-power of one cubic foot of water per minute under heads from 1 up to 1100 ft.

Heads in Feet.	Horse- power.	Heads in Feet.	Horse- power.
1	·0016098	320	·515136
20	·032196	330	·531234
30	·048294	340	·547332
40	·064392	350	·563430
50	·080490	360	·579528
60	·096588	370	·595626
70	·112686	380	·611724
80	·128784	390	·627822
90	·144892	400	·643920
100	·160980	410	·660018
110	·177078	420	·676116
120	·193176	430	·692214
130	·209274	440	·708312
140	·225372	450	·724410
150	·241470	460	·740508
160	·257568	470	·756606
170	·273666	480	·772704
180	·289764	490	·788802
190	·305862	500	·804900
200	·321960	520	·837096
210	·338058	540	·869292
220	·354156	560	·901488
230	·370254	580	·933684
240	·386352	600	·965880
250	·402450	650	1·046370
260	·418548	700	1·126860
270	·434646	750	1·207350
280	·450744	800	1·287840
290	·466842	900	1·448820
300	·482940	1000	1·609800
310	·499038	1100	1·770780

To reduce heads in feet to pressure in pounds multiply by ·434.

When the exact head is found in above table.

Example.—Have 100 ft. head and 50 in. of water. How many horse-power?
By reference to above table the horse-power of 1 in. under 100 ft. head is ·241470. This amount multiplied by the number of inches, 50, will give 12·07 horse-power.

Again—have 200 ft. head and 25 cubic ft. of water. How many horse-power
1 cubic ft. under 200 ft. head = ·321 horse-power. Therefore 25 cubic ft. \times ·321
= 8 horse-power. *Answer.*

When exact head is not found in table.

Take the horse-power of 1 in. under 1 ft. head and multiply by the number of inches, and then by number of feet head. The product will be the required horse-power.

Miner's inch measurement.—The most scientific way of measuring the quantity of water is doubtless that which gives the answer in cubic feet, and this is indeed the most useful. It is, however, sometimes the custom to calculate and pay for the use of water by the "miner's inch," a somewhat indefinite term, which varies in its application in different countries; as, for instance, the California Water Companies do not all use the same head above the centre of the aperture from which the water flows, and the inch varies from 1.36 to 1.73 cubic ft. per minute each, but the most common measurement is through an aperture 2 in. high and whatever length is required, and through a plank

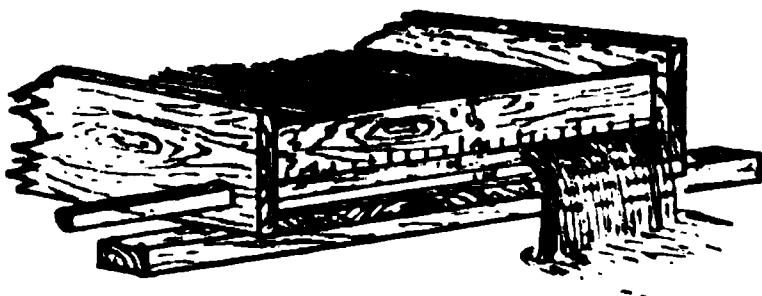


FIG. 22.—MINER'S INCH MEASURING BOARD.

1½ in. thick. The lower edge of the aperture should be 2 in. above the bottom of the measuring box, and the plank 5 in. high above the aperture, thus making a 6-in. head above the centre of the stream. Each square inch of this opening represents a miner's inch, which is equal to a flow of 1½ cubic ft. per minute.

Time is not to be considered in any calculation based upon a miner's inch measurement.

The apparatus employed to measure the water is shown in fig. 22. It consists simply of a sluice, *a*, bringing the supply of water, closed at the end by a board, *b*, in which is a long narrow opening, *c*, usually 2 in. or 4 in. deep, and this opening can be regulated by means of the sliding shutter, *d*. The dimensions are shown on the illustration. The quantity of water is calculated according to the area of the opening, each square inch of which

is a "miner's inch," and allows about $1\frac{1}{2}$ cubic ft., or $9\frac{1}{3}$ gallons, to pass through per minute. The following table will give the quantities in cubic feet which will pass through an aperture as described, per minute.

Length of Opening in Inches.	Openings 2 inches High.			Openings 4 inches High.		
	Head to Centre, 5 inches.	Head to Centre, 6 inches.	Head to Centre, 7 inches.	Head to Centre, 5 inches.	Head to Centre, 6 inches.	Head to Centre, 7 inches.
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
4	1'348	1'473	1'589	1'320	1'450	1'570
6	1'355	1'480	1'596	1'336	1'470	1'595
8	1'359	1'484	1'600	1'344	1'481	1'608
10	1'361	1'485	1'602	1'349	1'487	1'615
12	1'363	1'487	1'604	1'352	1'491	1'620
14	1'364	1'488	1'604	1'354	1'494	1'623
16	1'365	1'489	1'605	1'356	1'496	1'626
18	1'365	1'489	1'606	1'357	1'498	1'628
20	1'365	1'490	1'606	1'359	1'499	1'630
22	1'366	1'490	1'607	1'359	1'500	1'631
24	1'366	1'490	1'607	1'360	1'501	1'632
26	1'366	1'490	1'607	1'361	1'502	1'633
28	1'367	1'491	1'607	1'361	1'503	1'634
30	1'367	1'491	1'608	1'362	1'503	1'635
40	1'367	1'492	1'608	1'363	1'505	1'637
50	1'368	1'493	1'609	1'364	1'507	1'639
60	1'368	1'493	1'609	1'365	1'508	1'640
70	1'368	1'493	1'609	1'365	1'508	1'641
80	1'368	1'493	1'609	1'366	1'509	1'641
90	1'369	1'493	1'610	1'366	1'509	1'641
100	1'369	1'494	1'610	1'366	1'509	1'642

NOTE.—The apertures from which the above measurements were obtained were through material $1\frac{1}{4}$ in. thick, and their lower edge 2 in. above the bottom of the measuring box, thus giving full contraction.

CHAPTER: II.

WIND ENGINES AND VENTILATING MACHINERY.

Wind as a Motive Power—Modern Wind Engine—Velocity of Wind and Pressure per Square Foot—Horsepower of Windmills, and Cost—The Ventilation of Mines—Box Ventilation—Fan—Root Blower—Guibal Fans—Other Machines—Comparative Table of Ventilating Machines—The Measurement of Ventilation—Approximate Measurements—The Anemometer.

WIND AS A MOTIVE POWER.—The success with which windmills have been used for pumping and drainage purposes in Holland, and also in the county of Norfolk, leads one to believe that they could be employed for the same purpose in mining. As a matter of fact, they are but very little used in connection with mines, and this perhaps is due to their unreliability, and to the fact that most mines are situated in mountainous districts, where, owing to the excessive force of the sudden gusts of wind, these mills would be liable to serious accident, if not to total destruction.

FIG. 23.—WIND ENGINE.

30 WIND ENGINES AND VENTILATING MACHINERY.

TABLE SHOWING THE VELOCITY OF THE WIND OF PRESSURE
PER SQUARE FOOT.

Miles per Hour.	Feet per Minute.	Feet per Second.	Force in lbs. per Square Foot.	Description.
1	88	1'47	'005	Hardly perceptible.
2	176	2'93	'020	Just perceptible.
3	264	4'4	'044	
4	352	5'87	'079	
5	440	7'33	0'123	Gentle breeze.
10	880	14'67	0'492	Pleasant breeze.
15	1,320	22'0	1'107	
20	1,760	29'3	1'968	
25	2,200	36'6	3'075	British gale.
30	2,640	44'0	4'428	High wind.
35	3,080	51'3	6'027	
40	3,520	58'6	7'872	
45	3,960	66'0	9'963	Very high wind.
50	4,400	73'3	12'300	Storm.
60	5,280	88'0	17'712	Great storm.
70	6,160	102'7	24'108	
80	7,040	117'3	31'488	
100	8,800	146'6	49'200	Hurricane.

There are some situations, however, and many uses, to which they can be put; amongst others that of driving dynamos for feeding accumulators, so that a short description will not be out of place in a book on mining machinery.

The ordinary form of windmill, as used for grinding corn, is doubtless familiar to most. The modern form of wind engine is shown in fig. 23, the sails of which are made up to 35 ft. in diameter, beyond which the four-armed windmill is to be preferred.

The sails are mounted on the top of an iron and mild steel latticework, and the shaft on which they work gears into a perpendicular shaft, from the foot of which again any machinery can be driven either by belt or bevel gearing.

The main sails are kept facing the wind by means of the small directing wheel in the rear, which drives a small worm-wheel gearing into fixed teeth on the top of the framework. The main sail is composed of a number of separate boards which can be fully opened when it is required to stop the mill, or partially closed, according to the force of the wind, by means of the chains hanging in the rear, which are connected with the sails through a system of levers worked by a rod passing through the centre of

the main shaft. An automatic governing arrangement can be supplied if required, so that the sails will adjust themselves to the variations in the force of the wind, and so maintain an approximately even rate of speed. The pressure of the wind per square foot is a quantity ever varying according to the speed at which the wind is travelling, and this may be ascertained from the table given above. The horse-power of a windmill may be obtained from the following formula (Molesworth):—

HP = Horse-power.
 V = Velocity of wind in feet per second.
 A = Total area of sails.

$$HP = \frac{A V^3}{1,080,000} \qquad A = \frac{HP \ 1,080,000}{V^3}$$

The following particulars will show the approximate horse-power, size, and cost of wind engines such as that shown in the illustration:—

Approximate Horse-power, Breeze 14 miles per Hour (Pleasant Breeze).	Diameter of Wind Engine.	Price of Wind Engine, without Supports.	Price of Iron and Steel Tower.
$\frac{1}{4}$ horse-power.	13 feet.	£45	£25
$\frac{1}{2}$ "	14 "	50	27
1 "	16 "	60	30
2 "	20 "	90	40
3 "	24 "	110	45
4 "	28 "	180	50
4½ "	30 "	200	55
6 "	35 "	250	60

THE VENTILATION OF MINES.—The ventilation of the metalliferous mines is not surrounded with the same difficulties and dangers as is that of collieries, where, owing to the large quantities of gas given off by the coal, most careful attention has to be paid to the question.

As regards metalliferous mines, especially when they are once opened up, the natural ventilation due to the difference of temperature between the air underground and that at the surface is generally sufficient to supply the wants of the men and remove the smoke and gases produced when blasts are fired.

The general use of rock drills worked by compressed air has also greatly improved the ventilation in the end of levels and in

sinking shafts. Nevertheless, during the process of opening out the mine, especially where rock drills are not employed, means must be resorted to in order to produce a current of air ; while in some mines, especially those in a limestone formation, where large volumes of carbonic acid gas are frequently given off, permanent ventilating machinery must be provided.

A very simple appliance is used in Cornwall for ventilating the end of a level driven from a shaft in which pump rods are working. It consists of two tubs or boxes fitting one inside the other, the outer one being half filled with water and having a pipe running up from the centre of the bottom to about the level of the edge of the tub. On the top of this pipe an ordinary leather clack valve is fixed, opening outwards. The smaller tub is inverted,

FIG. 24.—ROOT'S POSITIVE BLOWER.

open mouth being downwards, and in the closed top an opening is made also, provided with a clack valve working outwards. An iron rod connects the centre of this tub with the pump rods in such a manner that during their ascent they lift the inner tub and so cause a vacuum to form inside it, into which the air from the level rushes through the central pipe of the outer tub. At the downstroke the air is forced out through the valve in the top of the inner tub.

The depth of the tubs should be greater than the length of the stroke of the pump, so that the inner or working tub may never be lifted above the level of the water in the outer or fixed tub.

The valves should be light, and if possible counterbalanced, in order that the best effect may be obtained. The Struvé ventilator is founded on this principle, and for colliery work is made in sizes

up to 22 ft. in diameter, capable of giving a theoretical quantity of air of from 20,000 to 100,000 cubic ft. per minute.

The machine most commonly used where small quantities of air only are wanted is the ordinary fan, driven by hand either from a belt wheel or through gearing, and is indeed so very well known, and often constructed on the mine itself, that I will pass on to the more powerful Root blower, which is largely used for ventilation purposes, and is shown in elevation and section in figs. 24 and 25. This blower may be used either for forcing the air into a mine or for drawing it out with equally good effect.

The outer casing is of cast iron, with the cylindrical parts bored out and the head plates faced. The internal operating parts consist simply of two revolving

FIG. 25.—CROSS SECTION ROOT'S POSITIVE BLOWER.

wings, each cast entirely in one piece, of the section shown in fig. 25.

The wings do not touch in running, but turn as closely as possible together without coming into contact. They are connected together by two cogwheels of equal diameter, and driven by the pulleys shown in the drawing. All the friction is confined to the journals and cogwheels. As long as these are kept in order by perfect lubrication, and not allowed to heat or wear, the blower will continue in order without limit as to time.

The principal sizes in which these ventilating machines are constructed are given in the following table, as well as the power and speed necessary to work them :—

No.	Required Horse-power.*	Displacement per Revolution Cubic feet.	Minimum Speed.	Maximum Speed.	Size of Pulley. Inches.	Diameter of Discharge. Inches.	Weight. Pounds.	Price.
1	1	$\frac{3}{4}$	300	350	12 x 2 $\frac{1}{2}$	5	360	£27
2	2	1 $\frac{1}{2}$	250	300	14 x 2 $\frac{3}{4}$	6	667	39
3	3 $\frac{1}{2}$	3	225	375	16 x 3 $\frac{1}{2}$	8	1,400	52
4	5 $\frac{1}{2}$	5	200	325	20 x 4 $\frac{1}{2}$	10	1,836	68
5	8	8	175	300	24 x 5 $\frac{1}{2}$	12	2,740	93
6	11 $\frac{1}{2}$	13	150	275	30 x 6 $\frac{1}{2}$	14	4,011	121
7	17 $\frac{1}{2}$	23	125	250	36 x 7 $\frac{1}{2}$	16	6,385	185
8	27	42	100	200	42 x 8 $\frac{1}{2}$	20	10,811	270
9	40	65	75	175	48 x 10 $\frac{1}{2}$	24	16,000	360

* Horse-power calculated on $\frac{1}{2}$ lb. pressure maximum speed.

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The machines should be fixed on a firm foundation in a dry place, and perfectly level lengthwise. When used for blowing, the air can be conveyed to them through trunks or boxes, and it is of the utmost importance that the pipes conveying the air under pressure from the blower should be perfectly tight. Leaky air pipes are often used, and often result in the loss of one-half or more of the air. Iron piping of large diameter, with air-tight joints, is the best, as wooden air-pipes cannot be made sufficiently tight.

The lowness of the first cost and the ease with which these blowers are erected have led to their being largely used for tunnelling and sinking purposes and the preliminary work of opening up a mine.

FIG. 26.—GUIBAL VENTILATING FAN.
END VIEW.

FIG. 27.—THE GUIBAL FAN. SIDE
VIEW.

For the permanent ventilation of a mine when the natural draught is insufficient, the machine which has met with most favour is the Guibal, which is shown in figs. 26 and 27. The fan varies from 20 to 50 ft. in diameter, and has from 8 to 10 blades inclined backwards and curved at the tips, so interlaced as to form a structure of great strength. The air can enter at one or both sides. As a rule, one side is placed in communication with the mouth of the shaft and the other is closed by a wall through which the axle of the fan passes, and is driven direct by a single cylinder engine. The general dimensions are given in the table on page 36.

The air is discharged at one particular place, to be determined by experiment, and which is closed by an adjustable shutter, so that the exit opening may be regulated into an expanding chimney

larger at the top than the bottom, the effect of which is to gradually reduce the velocity before reaching the outside, where the current is out of the influence of the fan.

A Guibal fan, 30 ft. diameter by 13 ft. wide, driven at a velocity of 100 revolutions per minute, will discharge 100 to 120 cubic yds. of air per second, where a depression of the water-gauge of $1\frac{1}{4}$ to $1\frac{1}{2}$ in. is sufficient.

The percentage of useful effect of the Guibal ventilation at the Hilda Colliery in South Shields is 40, but at the Pemberton Colliery near Wigan it is 52.95.

The other ventilating fans before the public are those connected with the names of Waddle, Schiele and Capell, in addition to which there is the Struvé machine, already mentioned, and the Nixon. This latter is a horizontal double-acting air-pump, with two rectangular pistons of large size supported on wheels which run on rails. The piston works in a closed chamber, the lower half of which is in connection with the pit when the inlet valves are open, and with the atmosphere through the outlet valves in the upper half.

A Committee of the North of England Institute of Mining Engineers recently made some investigations as to the efficiency of different kinds of mechanical ventilators as used for collieries* ; but the information thus collected will be of great utility to metalliferous miners, and is contained in the tabular statement (see next page) compiled from the Report of the Committee by Mr. H. Davey, of Leeds.

The Measurement of Ventilation.—The explosive gases met with in collieries have made it necessary that a daily record shall be taken of the quantity of air passing through the workings and of the atmospheric conditions as indicated by the barometer and thermometer.

In metalliferous mining, on the contrary, but little attention is unfortunately paid to the state of the ventilation, until it forces itself into notice by the dimness of the lights or the hanging of powder smoke.

The generally-accepted rule in collieries where there is no escape

* See "Transactions of North of England Institute of Mining Engineers," vol. xxx., 1880-1.

EFFICIENCIES OF MECHANICAL VENTILATORS.

No.	Name of Ventilating Machine.	DIMENSIONS OF VENTILATING MACHINES.					DIMENSIONS OF ENGINES.				GENERAL REMARKS.		
		Diameter.	Width, etc.	Theoretical Displacement per Minute.	Diameter of Inlet.	Weight.	No. of Cylinders.	Diameter of Cylinders.	Length of Stroke.	Direct Acting or Gearing.	Volume of Air per Minute.	Mean Water-Gauge Pressure.	Percentage of Useful Effect.
		ft.in.	ft. in.	Cubic feet.	ft.in.	Tons.		ft.	ft. in.		Cubic Feet.	Inches.	Per Cent.
1	Guibal Fan	50 0	12 0	—	15 0	50	1	42	3 6	Direct	108,422	3'30	40'00
2	Guibal Fan	46 0	14 10	—	13 0	—	1	36	3 6	Direct	246,509	1'85	52'95
3	Guibal Fan	40 0	12 0	—	14 0	24	1	36	3 0	Direct	170,581	1'46	47'95
4	Waddle Fan	45 0	Inlet 6 6 Periphery 1 5	—	15 0	—	1	32	4 0	Direct	163,312	3'08	52'79
5	Schiele Fan	12 0	2 1	—	—	—	1	25	2 0	2'57 to 1	157,176	1'91	46'12
6	Schiele Fan	9 6	Inlet 3 2 Periphery 1 8	—	8 0	—	1	20	1 8	2½ to 1	106,570	2'03	49'27
7	Lemierre Chamber Drum	22 6 15 0	Height 32 0	rev. 9'9 108,900	—	—	1	55	6 0	Direct	47,307	1'37	23'40
8	Struvé 2 Pistons	18 3	Stroke 7 0	6½ 47,827	—	—	1	24	4 4½	4 to 1	43,793	5'11	57'80
9	Nixon 2 Pistons long. 2 Pistons high	30 0 20 0	Stroke 7 0	7'19 120,790	—	—	1	36	6 0	Direct	72,595	2'74	45'91
10	Root 2 Drums	25 0	13 0	16'71 96,918	—	—	2	28	4 0	Direct	89,772	3'29	47'84
11	Cooke 2 Drums Casing	15 0 22 0	11 6	17'92 80,640	—	—	1	25	3 6	Direct	54,190	1'12	37'33
12	Goffint 2 Pistons	13 2	Stroke 10 7½	9½ 53,020	—	—	2	15½	10 7½	Direct	36,286	0'71	25'79

of fire-damp is that a minimum of 100 cubic ft. of air per minute is required for each man and boy, and in order that the manager or captain of a metalliferous mine may ascertain for himself, without the use of instruments, the quantity of air passing at any given moment, I annex the two following general methods which were fully described in a paper read by Messrs. Atkinson and Daglish before the Birmingham meeting of the North of England Institute of Mining Engineers in 1861 :—

(1) "Travelling at the same velocity as the current, and noting the distance passed over in a unit of time."—This was a very primitive mode, but no doubt when used it gave a fair approximation to the truth ; for recent experiments have proved that it admitted of great accuracy for velocities up to 400 ft. per minute. It was open to many objections, and would be utterly unsuited to the large mines now existing, since it would be impossible to walk as quickly as the currents travel in the principal splits, and running is not a sufficiently steady pace for the purpose. The process was as follows : Choice was made of a part of the gallery forming the air-way having as uniform sectional dimensions as could be found, and, after measuring off a distance of a hundred or a hundred and fifty yards in length, the operator took a lighted candle and walked in the direction of the current, fully exposing the flame to its influence, but taking care to move at such a rate that the flame would burn in an upright position without being deflected from the vertical, either by the current or by the progress of the person carrying it. The time required to traverse the distance measured off being carefully noted by a seconds watch, the average rate of walking was thereby determined, and three or four trials served to give the assumed velocity of the air-current. This, multiplied by the average sectional area of the part of the air-way selected for experiments, was taken to represent the quantity of air passing in the unit of time.

(2) "Determining from observation the rate at which small particles are carried along by the current, and assuming their velocities to be identical with that of the air-current itself."—Until recently observations of the velocity of the smoke from an

exploded charge of gunpowder, in a part of the gallery of nearly uniform sectional area, were the means most generally adopted in the coal mines of this country for ascertaining the velocity of air-currents. They are still considerably used, and so far as regards shaft velocities, they remain the only method. For this purpose an even part of a road should be selected, about 50 to 60 ft. in length, and its cubical contents in feet ascertained. Then let off a flash of gunpowder at the windward end of the channel, and observe the number of seconds the smoke is in passing to the other end. Then say as the time (in seconds) in passing is to the cubic area, so is 60 seconds to the number of cubic feet passing per minute.

Example: Length of channel selected, 60 ft. ; height, $5\frac{1}{2}$ ft. ; width, 6 ft. ; time in passing, 4 seconds. What is the amount of air?

$60 \text{ ft.} \times 5\frac{1}{2} \text{ ft.} \times 6 \text{ ft.} = 1980 \text{ cubic ft. area ; and as } 4 : 1980 :: 60 : 29,700 \text{ cubic ft. per minute.}$

These methods are sufficiently exact for all ordinary purposes, but are liable to various sources of error, though by the use of fixed quantities and distances, and the avoidance of extreme velocities, an approximation to accuracy may be obtained. To secure this, the following precautions are recommended :

(a) Always to use one cubic inch of gunpowder as a standard.

(b) The velocity of the current never to be less than 100 ft. per minute, nor to exceed 500 ft. per minute.

In order to attain this, a gallery of such area must be selected as will afford this velocity of current.

(c) The time not to be less than 12 seconds nor to exceed 30 seconds.

(d) To explode the gunpowder 10 ft. to the windward of the first mark. Therefore, in slow currents of from 100 to 250 ft. per minute velocity, the distance to be taken over which the smoke passes will be 50 ft. ; and for the higher velocities, of from 250 to 500 feet, the distance will be increased to 100 ft.

The instrument used in connection with ventilation, for the purpose of ascertaining the quantity of air passing per minute, is

called the Anemometer, and is represented in fig. 28. It consists essentially of six vanes made of thin sheet brass; these are delicately mounted on a centre moving freely within a brass ring. It is carried by the handle, and indicates the most gentle current, the rate at which the van revolves being noted by the index in the centre of the figure.

To ascertain the number of cubic feet of air passing per minute, multiply the velocity per minute, or, in other words, the recorded number of revolutions by the sectional area of the air-way in feet, and the result will be the quantity in cubic feet.

For the purpose of temporarily increasing the ventilation in a shaft the pump cisterns may be allowed to run over, and so create a waterfall which carries a certain quantity of air down with it, or a steam-jet directed upwards may be placed in the shaft just as a blast-nozzle is placed in the chimney of a boiler. Neither of these methods are economical, and must be regarded only as temporary expedients. Where fuel is abundant, a fire hung in the upcast shaft is an effectual means, but is rarely used in metalliferous mines because of the cost of coal.

FIG. 28. —THE ANEMOMETER.

CHAPTER III.

STEAM BOILERS, STEAM ENGINES, AND OIL ENGINES.

Boilers—The Egg-end—Cornish—Lancashire—Horse-power of Boilers—Chimneys, Heights of—Locomotive Multitubular Boilers—Vertical Boilers—Stoking—Steam Engines for Driving Mills—Horse-power of Engines—Mean Effective and Terminal Pressures—Condensing and Non-condensing Engines—The Corliss Engine—The Compound Engine—The Priestman Oil Engine.

BOILERS.—Great ingenuity has been displayed by the various boiler-makers, in order to obtain the maximum of evaporative power per pound of fuel, which is the standard of efficiency of a boiler. Generally speaking, boilers may be roughly divided into three classes, of which the Cornish and Lancashire represent the type used for permanent works, the locomotive multitubular boiler for less permanent work and situations where transport is difficult, and the vertical for temporary use.

The plain cylindrical egg-end boiler, from 20 ft. to 30 ft. long \times 6 ft. or 8 ft. diameter, fired externally, is now but little used, and in mining would, indeed, be too expensive, owing to its excessive consumption of fuel, its evaporative power being only about 7 lbs. or 8 lbs. of water per lb. of fuel consumed, as compared with the 10 lbs. to 12 lbs. which are obtained with Cornish or Lancashire boilers.

The Cornish boiler differs from the egg-end in having flat ends and one internal flue passing from end to end with the object of increasing the heating surface.

The Lancashire boiler again differs from the Cornish in having two internal flues running from end to end, across which again

"Galloway tubes" are fitted, as shown in fig. 29. These tubes are used both in the Cornish and Lancashire boilers, and their effect is to increase the heating surface, create a better circulation of water, and also to strengthen the main flue in which they are placed. The Cornish boiler is suitable for small powers, as, if

FIG. 29.—CROSS SECTION AND FRONT ELEVATION OF LANCASHIRE BOILER.

made for great powers, an excessively large furnace flue would be required in order to give sufficient grate surface; and this again, unless made of very thick plates, would be liable to collapse.

The fire grates are fixed inside the main flues, and in practice are from 5 ft. to 7 ft. long. The products of combustion pass from the fire grate through the internal flue and around the

Galloway tubes to the back end of the boiler; then dividing, they return to the front along two external side flues. Here they pass

down to the bottom flue, and re-uniting, pass together underneath the boiler to the chimney.

The boiler is usually constructed of iron or mild steel plates, and the joints are riveted together by either a single or double row of rivets. Egg-end boilers require no stays on the inside, but the flat ends of Cornish and Lancashire boilers both need gusset stays, shown at E in fig. 30.

The makers furnish plans for the setting of these boilers. The main objects to be aimed at, moreover, are summed up as follows by Mr. Caleb Pamely, the author of "The Colliery Manager's Handbook,"* in which will be found an excellent treatise on the construction and erection of boilers.

1. The circulation of the gases in contact with the shell, so that the heat of the fuel is utilised to its full extent.

2. The distribution of these gases in such a manner as to equalise the temperature of the shell as far as practicable.

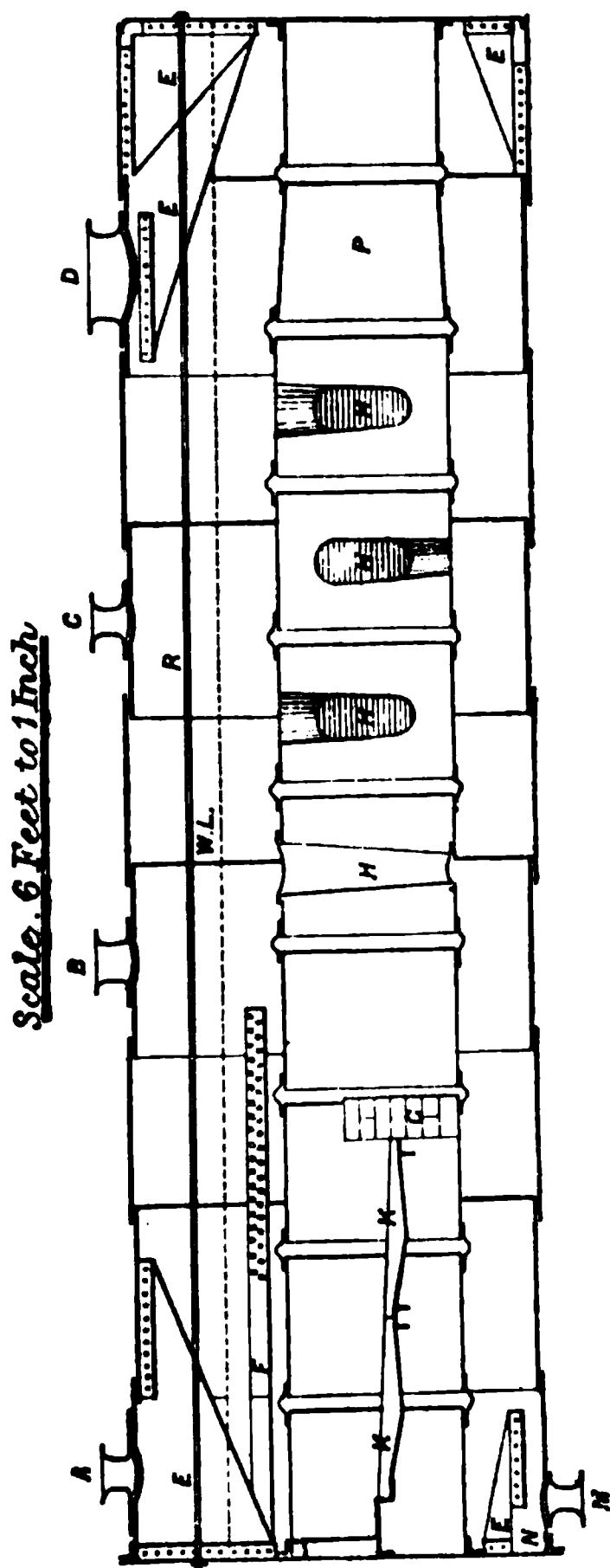


FIG. 30.—LONGITUDINAL SECTION OF CORNISH BOILER.

* Published by Messrs. Crosby Lockwood and Son.

3. The arrangement of flues to give full access to a person to make an inspection of every part of the outside of the boiler.

4. The prevention of loss of heat by radiation from surfaces not exposed to the hot gases.

The general arrangements of a Lancashire boiler will be gathered from figs. 29 and 30, which show the front elevation, side elevation, and longitudinal section of a boiler of this class, and from the following description, which is extracted from the book just mentioned.

The furnace of a Cornish or Lancashire boiler consists of a mouthpiece, having doors provided with a sliding grid, as shown in the front elevation, fig. 29. The furnace bars are made in two lengths, as shown at *κ κ*, fig. 30. At the front end these bars rest upon a dead plate, and at the back at a slightly lower level, so that the bars may incline inwards; they are supported by the firebrick bridge, *G*, either on a ledge formed on the bridge for that purpose, or on a bearer built into it. In the middle, at the joint of the two lengths, the bars are supported by a cross bearer.

The bridge is usually built entirely of firebrick to within about 20 in. of the crown of the internal flue, but sometimes a cast-iron stool is used to carry both the furnace bars and the firebrick. The stool is provided with a sliding door, by means of which the admission of air to the furnace flue is regulated from the furnace mouth.

Mechanical feeders may be used for stoking, but they are objectionable on account of their complicated mechanism and the power required.

In fig. 30, *A* and *C* are the blocks for the safety valves, a dead weight valve being placed at *A*, and a Hopkinson double safety valve at *C*.

B is the block for the stop valve, to which is also fitted a perforated or anti-priming pipe inside the boiler, but not shown in the drawing.

D is the manhole block. It is usually oval, but sometimes circular in shape, and is large enough to admit a man to the interior of the boiler to clean and repair it. It is placed in any convenient position on the top of the boiler.

E are the gusset stays, *R* longitudinal stay.

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WL is the water level in the boiler. Modern practice fixes the low water line at 4 in., and the working level at 9 in. above the furnace crown.

H Galloway tubes.

K the furnace bars.

G the firebrick bridge.

P the internal flue, the rings being welded and connected to each other by the bowling hoop-expansion joint.

M is the blow-off cock.

F the feed pipe, extending 8 ft. or 10 ft. into the boiler, and having the inside portion perforated to allow of a gentle distribution of the water all around it.

N a mudhole door for the discharge of sediment from the boiler, shown also in the front elevation, fig. 29.

In fig. 29 will also be seen the feedwater pipe and valve, the two glass water-gauges, two gauge cocks, the furnace doors, blow-off cock, and the cleaning-flue doors.

Lancashire boilers work at 110-lb. pressure per square inch, and are at present made to the following dimensions:—

Length, 30 ft.; diameter of shell, 8 ft.; diameter of internal tubes, 3 ft. 3 in.; number of shell rings, 9, made of mild steel, having a tensile strength of 30 tons to the square inch.

Two plates in each ring $\frac{5}{8}$ in. thick; circular seams, lap-jointed double zig-zag riveted, $3\frac{1}{4}$ in. pitch, $1\frac{1}{4}$ in. line to line horizontal seams, butt-jointed, with inside and outside strap plates $\frac{1}{2}$ in. thick, pitch $3\frac{1}{8}$ in., $1\frac{7}{8}$ in. line to line in the outer lines, $2\frac{1}{2}$ in. line to line in the centre line. Rivet holes $\frac{15}{16}$ in., all drilled in position. Diameter of rivets $\frac{7}{8}$ in. of mild steel, machine-riveted. End plates of mild steel $1\frac{1}{8}$ in. thick, the back plate flanged, the front single riveted to shell angle iron 5 in. \times 3 in. \times $\frac{3}{4}$ in. Internal tubes of mild steel $\frac{7}{16}$ in. thick, 3 ft. 3 in. diameter, the plates having a tensile strength of 22 tons per square inch. Internal tube rings, hand welded, flanged and attached by $3\frac{1}{2}$ in. \times $3\frac{1}{4}$ in. \times $\frac{5}{8}$ in. angle irons to the end plates.

Five gusset stays at the front and back end plate above the tubes and two below, and one centre gusset. The boiler is subjected to an hydraulic test of 250 lb. to the square inch.

A boiler should be tested to at least double the pressure it is

intended to work at before being sent from the works, an hydraulic pump being used for the purpose, and a close examination for leakages being maintained throughout the test.

According to Molesworth, each nominal horse-power of a boiler requires—

- 1 cubic foot of water per hour.
- 1 square yard of heating surface.
- 1 square foot of fire-grate surface.
- 1 cubic yard capacity.
- 28 square inches flue area ; 18 inches over bridge.

For cylindrical double-flued boilers an approximate rule for ascertaining the nominal horse-power is

$$\frac{\text{Length} \times \text{diameter}}{6} = \text{Horse-power.}$$

According to this rule the horse-power of the Lancashire boiler just described would be $\frac{30 \times 8}{6} = 40$ horse-power.

It is not usual to make these boilers of a larger size than this, as it is considered more advantageous to increase their number than to increase their dimensions.

An indispensable adjunct of the permanent boiler is the chimney, which must be so proportioned as to height and area as to create a sufficient natural draught for the needs of the furnaces. The following table will give the proper diameter and height of a chimney for any kind of fuel :—

Nom. HP. of Boiler.	Height of Chimney in feet.	Inside Diameter at Top.
		ft. in.
10	60	1 6
12	75	1 8
16	90	1 10
20	99	2 0
30	105	2 6
50	120	3 0
70	120	3 6
90	120	4 0
120	135	4 6
160	150	5 0
200	165	5 6
250	180	6 0

The diameter at the base is $\frac{1}{10}$ th to $\frac{1}{12}$ th the height, and the batter about 0·3 in. to a foot. The thickness of the brickwork from the top downwards is 1 brick for the first 25 ft., $1\frac{1}{2}$ brick for the second 25 ft., and so on increasing by $\frac{1}{2}$ brick for each 25 ft. from the top.

Locomotive Multitubular Boilers.—This type of boiler is shown in fig. 42, and its construction being similar to that of a locomotive boiler is well known.

The great advantages attaching to their use for mining purposes are that they require no setting, occupy but small space in comparison with the power developed, have very large heating surfaces, and are the most economical producers of high-pressure steam. They are also easily transported, for which purpose they may either be mounted on a waggon, or fitted with wheels of their own. An iron chimney is used, and so dispenses with a costly erection in brick, which, on the closure of a mine, is often left standing as a valueless monument to the departed activity of the place.

These boilers are made in all sizes, from $2\frac{1}{2}$ to 65 horse-power nominal; those under 20 horse-power are made for a working pressure of 80 lb., and those above for one of 100 lb. per square inch; and can be grouped together so as to generate steam for any required horse-power.

Vertical boilers are used for engines of small power, and are generally fitted either with Galloway tubes, or else with a large number of small vertical tubes, through which the hot gases pass into a smoke box above, and at the foot of the chimney. There are many other types which have been designed for special purposes, such as the water-tube boilers, in which the hot gases from the furnace play about a large number of parallel tubes, through which water is passed, and which are connected with a steam receiver above. These are very rapid generators of steam, and are suitable for special purposes. Their portability has caused them to be frequently used for mining purposes.

Boilers are frequently left in the charge of untrustworthy and unskilled attendants, in whose hands they quickly deteriorate, and the length of their life reduced considerably from a maximum of thirty years.

Stoking does not consist solely in shovelling on fuel at irregular intervals, and filling up with water as soon as convenient after it has gone out of sight in the gauge glass. Unless care is used in the firing, much smoke is created. The fuel should be fed frequently, and in small quantities, which should be evenly spread over the surface of the fire-grate so as to leave none of the bars visible.

Clinkers should be removed as soon as formed, the steam maintained at an even pressure, and not allowed at one moment to blow off vigorously, while at the next it is below working pressure: a state of things caused by spasmodic stoking, and intense firing at intervals.

The feed water should be heated by means of the exhaust steam, and the level of the water in the gauge carefully watched and maintained at frequent intervals.

The boilers must be blown off, say, once a week, or fortnightly, according to the quality of the water used, and then allowed to cool gradually before being filled up with a fresh supply. If artificial means are used to cool down a boiler, in all probability damage will be done by the rapid contraction of the plates; and again, when raising steam from cold water, rapid firing must not be allowed, as the opposite effect of expansion may create mischief.

In short, it will be more economical in the long run to pay good wages to an intelligent and skilled stoker, rather than entrust a machine like a boiler with immense potentiality for dealing destruction around, to the first bumpkin who wants a job.

STEAM ENGINES FOR DRIVING MILLS.—Steam has been so largely used in mining operations, and for so long a time as a motive power for driving the winding and mill engines, that it is now almost assumed that, because a man is a miner, he is also practically acquainted with the working of engines. It is, however, impossible for any one to carry in his head all the formulæ in connection with steam, and for this reason I will give a few of those in most frequent use before proceeding to describe the type of engine now in use.

The power of an engine is compared with that of a horse, and this latter is assumed to be that equal to raising a weight of 33,000 lb. one foot high in a minute. The term “nominal”

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horse-power, as applied to engines, is vague and misleading, and varies according to the make of the engine.

The actual or I.H.P.—indicated horse-power—of an engine is from two-and-a-half to three times the nominal, so that the I.H.P. alone should be used as a standard.

For non-condensing engines the actual horse-power may be obtained by the following formula :—

- Let p = the mean effective pressure of steam in lb. per square inch,
 less 3 lb. per square inch frictional allowance.
 „ A = the area of the cylinder in square inches.
 „ L = length of stroke in feet.
 „ N = the number of strokes per minute = revolutions $\times 2$.
 „ HP = horse-power.

$$HP = \frac{p L A N}{33,000}$$

The mean effective pressure is the average pressure of the steam throughout the stroke, and may be obtained from the following table, according to the initial pressure in cylinder, and the point at which the steam is cut off.

The area of the cylinder is the diameter in inches, squared—that is, multiplied—by itself, and then by .7854.

Condensing engines are not used for winding purposes, owing to the rapidity of the motion, and the frequent stopping and starting. For other purposes, such as pumping and driving the mill, or air compressors, they can be used to great advantage, especially where fuel is scarce and expensive.

The effect of a good condenser and air-pump should be to make available 10 lb. more mean effective pressure with the same terminal pressure, or to give the same mean effective pressure with a correspondingly less terminal pressure.

When, for example, the load on the engine requires 20 lb. M.E.P., the condenser does half the work; at 30 lb. one-third; at 40 lb. one-fourth, and so on. It is safe to assume that the condenser will save practically from one-fourth to one-third of the fuel, and it can be applied to any engine, cut-off or throttling, where a sufficient supply of water is available.

The amount of feed-water and coal consumed by an engine

varies greatly; between 20 lb. to 60 lb. of feed-water and from 2 lb. to 7 lb. of coal per I.H.P. per hour being required according to the make of the engine.

Condensing engines, in addition, require from 20 to 30 gallons of water to condense the steam represented by every gallon of water evaporated, or roughly from 1 to 1½ gallon per minute per I.H.P.

As a rule, the question of condensing or non-condensing is settled before the engine is ordered; but if it is desired to convert a non-condensing into a condensing engine, this can readily be done by the use of a separate condenser, either of the jet or the surface

MEAN EFFECTIVE AND TERMINAL PRESSURES.
POINTS OF CUT-OFF.

Initial Pressures.	1/4		1/3		1/2		2/3		3/4		Initial Pressures.	
	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.
40	13.46	11.79	17.34	14.49	20.75	17.11	23.70	19.80	26.22	22.44	30.50	27.78
45	16.15	12.87	20.39	15.81	24.13	18.67	27.32	21.61	30.08	24.49	34.75	30.33
50	18.85	13.94	23.45	17.13	27.50	20.24	30.94	23.42	33.95	26.55	39.00	32.88
55	21.54	15.00	26.50	18.45	30.87	21.80	34.56	25.25	37.81	28.60	43.25	35.43
60	24.24	16.08	29.56	19.77	34.24	23.37	38.18	27.04	41.68	30.66	47.50	37.98
65	26.93	17.15	32.61	21.09	37.61	24.94	41.80	28.85	45.54	32.71	51.75	40.52
70	29.63	18.23	35.67	22.41	40.98	26.51	45.42	30.66	49.41	34.77	56.00	43.07
75	32.32	19.31	38.72	23.73	44.35	28.07	49.05	32.47	53.27	36.82	60.25	45.61
80	35.02	20.39	41.78	25.05	47.72	29.64	52.68	34.28	57.14	38.88	64.50	48.16
85	37.71	21.46	44.83	26.37	51.09	31.20	56.31	36.09	61.00	40.93	68.75	50.70
90	40.41	22.54	47.89	27.67	54.46	32.77	59.94	37.90	64.87	42.99	73.00	53.25
95	43.10	23.62	50.94	29.01	57.83	34.33	63.57	39.71	68.73	45.04	77.25	55.79
100	45.80	24.70	54.04	30.33	61.20	35.96	67.20	41.52	72.60	47.10	81.50	58.34

The initial and M. E. P. in above table are pressures above atmosphere and for non-condensing engines; the terminal pressures are absolute—i.e., reckoned from perfect vacuum (14.7 lb. below atmospheric pressure).

type. The question as to which of these, depends upon the supply of water for condensation. If this is clean and such as can be used afterwards for feeding the boiler, then the jet condenser should be employed. If, on the other hand, the water is dirty and unfit for boiler use, the surface condenser is the most suitable. In the jet condenser the exhaust steam comes in contact with a spray of cold water, and, being condensed, creates a partial vacuum. An air-pump is required to remove the condensed steam and injected water, and this hot water can be used to feed the boiler.

In the surface condenser the exhaust steam does not come into direct contact with the cold condensing water. The condenser resembles a small multitubular vertical boiler, through the tubes of which a current of cold water is constantly circulated. The steam exhausts into the shell of the boiler, and coming into contact with the numerous cold tubes, is condensed, the same effect being obtained as in the jet condenser, except that the water from the condensed steam does not mingle with that employed for condensation. The hot water from the condensed steam is removed by means of an air-pump, and can then be returned to the boiler.

The pumps of independent condensers are driven either by means of a belt from a pulley on the engine shaft, or from a rocker shaft, which in turn is driven from a connecting rod attached to the crank pin of the engine. In other cases they are made completely independent of the existing engine, and the air-pump is driven by a small steam cylinder direct.

The Corliss Engine.—The competition between the various machinery makers with a view to produce the engine which would work with the greatest economy of fuel, has led to many and great improvements which are, indeed, too numerous to mention. As a type of the class of engine which has attained nearest to perfection, the Corliss may be taken as an example, and is made in three classes,—the improved non-condensing (fig. 31), the condensing, and the improved compound condensing; for which latter it is claimed that it consumes 30 per cent. less fuel than any non-condensing engine.

The special feature of the Corliss engine, which distinguishes it

FIG. 31.—IMPROVED CORLISS STEAM ENGINE.

M ENGINES, AND OIL ENGINES.

FIG. 33.—OUTLINE VIEW OF THE CORLISS ENGINE.

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REFERENCE NUMBERS TO FIGS. 32 AND 33.

Nos.

1. Cylinder.
2. Cylinder head.
3. False cylinder head.
4. Cylinder feet.
5. Walnut lagging for cylinder.
6. Stop valve.
7. Exhaust pipe.
8. Steam pipe.
9. Piston rod.
10. Cross head.
11. Wrist pin.
12. Connecting rod.
13. Steam valve.
14. Exhaust valve.
15. Valve bonnet.
16. Valve covers.
17. Long valve stems.
18. Short valve stems.
19. Steam valve cell cranks.
20. Exhaust valve levers.
21. Brass cut-off cams.
22. Steam valve rods.
23. Butt for steam valve rods.
24. Crab claw.
25. Crab claw spring.
26. Exhaust valve rods.
27. Butts for exhaust valve rods.
28. Compression dash-pot.
29. Dash-pot rod.
30. Wrist plate.
31. Wrist plate cap (brass).
32. Guide piece of engine frame.
33. Crank piece of engine frame.
34. Main bearing cap.
35. Rocker arm.
36. Rocker arm shaft.
37. Eccentric cam.
38. Eccentric strap.
39. Eccentric rod.
40. Second eccentric (or hook) rod.
41. Governor pulley.
42. Governor stand.
43. Governor spindle.
44. Governor collar.
45. Governor pulley shaft.
46. Governor connecting rod.
47. Governor bell crank.
48. Governor sleeve (brass).
49. Governor centre weight.
50. Governor knob.
51. Governor balls.
52. Governor arm.

Nos.

53. Governor hanger.
54. Governor cut-off rods.
55. Foundation bolts.
56. Crank pin.
57. Key for connecting rod strap.
58. Strap bolts for connecting rod.
59. Lower brass gib for cross head.
60. Upper brass gib for cross head.
61. Taper steel key (for piston rod).
62. Brass boxes for wrist pin.
63. Adjusting screw for wrist pin boxes.
64. Finished tap bolt for cylinder cover.
65. Main plunger of dash-pot.
66. Engine crank.
67. Crank shaft.
68. Top box for main pillow block.
69. Lower removable box for main pillow block.
70. Quarter boxes for main pillow block.
71. Parallel pieces for main pillow block.
72. Side wedges for main pillow block.
73. Bolts for holding down main cap.
74. Draw bolts for side wedges.
75. Bull ring.
76. Packing ring.
77. Steel set spring for packing.
78. Follower bolts.
79. Bull ring (end view).
80. Follower.
81. Piston head.
82. Lock for piston packing.
83. Compound cup for main bearing.
84. Cross head for plunger rods.
85. Plunger rods.
86. Stationary plunger.
87. Top air valve.
88. Bottom air valve.
89. Flange for wrist plate stud.
90. Taper stud for wrist plate.
91. Brass sleeve babbitted.
92. Brass sleeve collar.
93. Valve rod pins.
94. Blow block.
95. Hook pin thimble.
96. Hook pin.
97. Collar for hook pin.
98. Starting bar.

from all others, is the valve gear. There are two inlet steam valves, one of which is shown in section at 13 (fig. 32), and two exhaust valves, 14 (fig. 32). By means of the peculiar motion transmitted to these valves through the wrist plate, 30, driven by the eccentric rod, 49, the steam valves are opened quickly at the beginning of the stroke, thus allowing the steam to enter the cylinder at its full pressure, and are promptly closed at the point of cut-off. The exhaust valves also are opened swiftly and closed slowly, thus allowing free escape to all the steam and preventing back pressure on the piston.

At the point of cut-off, which is most effective at 2-10ths of the engine-stroke, but which is regulated by the load on the engine through the action of the governor, the steam valve is released, and at the same time is promptly closed by the dash-pot arrangement, 65 (figs. 32, 33). Expansion of the steam now commences, and continues until the exhaust valve opens at the end of the stroke, thus ensuring the greatest economy in its use.

The general arrangement of the various parts will be gathered from a study of figs. 32 and 33.

The Corliss engine is made in all sizes, either vertical or horizontal, according to the space at disposal, and the following particulars of a compound condensing engine of the twin type, shown in figs. 34 and 35, of 332 indicated horse-power, as erected at the works of the Blue Bird Mining Company, Limited, Butte, Montana, for driving a 90-stamp dry crushing mill, will be of interest.

The engines, made by Messrs. Fraser and Chalmers, are of the twin type, with the high-pressure cylinder working on one crank and the low-pressure on the other, the cranks being set at right angles to each other.

The heavy flywheel necessary for a single engine of the same power, in order to balance the action of the engine, is not required with the double engine, as one crank helps the other over the dead centres. It is replaced by two belt-wheels, each 18 ft. diameter by 31 in. face, placed one on each side of a central bearing, which thus relieves the main bearings of a considerable weight.

The high-pressure cylinder is 22 in diameter and the low-

pressure 38 in., the stroke of each being 60 in. Neither cylinder is steam-jacketed, and the steam passes into a receiver before it

FIG. 34.—COMPOUND TWIN CORLISS ENGINE. WITH RECEIVER, CONDENSER, AND HEATER PLAN.

FIG. 35.—ELEVATION OF TWIN COMPOUND CORLISS ENGINE.

enters the low-pressure cylinder. The volume of this receiver is about equal to that of the low-pressure cylinder.

The cut-off gear of the high-pressure cylinder is under the control of the governor, while that of the low-pressure is adjustable

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For the purpose of driving large mills some such an engine as the Corliss is undoubtedly the best. Where a smaller power is required some form of compound engine, such as that illustrated in fig. 36, is much used, either with or without a condenser, according to the abundance of the water supply.

The engine illustrated is one of Robey's new pattern compound fixed engines, which has been specially designed for use when a large power is required in a limited space.

The engine is erected on a massive cast-iron bed-plate, which gives it great stability. The crank bearings and all other working parts are of great size, thus allowing of smooth and cool running, and materially reducing the wear and tear.

These engines will run at comparatively high speed, and are fitted with an expansion governor, which controls automatically the point of cut-off in the high-pressure cylinder, and allows of variations being made in the load without perceptibly affecting the speed of the engine.

It is stated that the economy of fuel resulting from the use of these engines is very great, a large number of tests proving that less than 20 lb. steam (= 2 lb. coal) are required to develop 1 horse-power; thus 50 horse-power can be obtained from less than $\frac{1}{2}$ ton of coals per day of 10 hours. If there is sufficient water to allow of the use of a condenser a still greater economy of fuel may be attained to.

These engines are made in sizes varying from 8 to 50 horse-power, and the following list will give the approximate prices of the engines and boilers suitable for feeding them with steam :—

Nominal Horse-power.	Engine.	Extra for Jet Condenser if required.	Extra for Force Pump.	Extra for Foundation Bolts.	Boiler and Fittings.	Extra for Injector, if required.
8	£ 170	£ 30	£ 5	£ s. 2 10	£ 135	£ 8
10	190	30	5	2 10	145	8
12	210	40	8	2 10	157	8
16	248	50	10	4 10	192	10
20	285	60	10	5 0	235	10
25	345	75	10	5 10	295	15
30	400	80	15	5 10	345	15
40	585	90	15	7 10	480	15
50	705	105	20	8 10	540	18

In many cases the locomotive type of boiler with engine underneath, such as is shown in figs. 42 and 43, with winding drums attached, is used for driving small mills. The usual practice now, however, is to employ a compound engine such as the one described, and a detached locomotive multitubular boiler where powers under 50 horse-power are needed. Above that it is better to put down a permanent plant of Corliss engines and Lancashire boilers, especially if there are no great difficulties of transport to contend with.

The use of water-power for driving mills is described in Chapter I., and electricity as a motive power is explained in Chapter XXVII.

PRIESTMAN'S OIL ENGINE.—The ordinary form of gas engine cannot often be employed in connection with metalliferous mines, as these are usually situated far away from any source of gas. A new motor, however, has recently come into the market which can, I think, be utilised for the purposes of pumping, winding, and hauling, with as great advantage in metal mining as it has already met with in collieries for like purposes. This is the oil engine, patented and manufactured by Messrs. Priestman Bros., Ltd., of Hull, in all convenient sizes up to 25 horse-power ; and as it will be a novelty to some of my readers, I will give a somewhat full description of it, and would refer them to the "Proceedings of the Institution of Civil Engineers" for March 8th, 1892, for the more complete details which they will there find in a paper by Prof. W. C. Unwin, B.Sc., F.R.S., on the subject.

Referring to fig. 37, which is a sectional view of the engine, *Z* is the working cylinder ; *X* is the piston ; *K* the clearance space into which the air and vapour are compressed before explosion. At *Y* is the supply tank for oil. In order to deliver the oil from this tank to the spray-maker, *S*, or starting lamps, *EE*, an air pressure is maintained in the tank, which is produced initially by the small hand pump, *M*, and afterwards maintained by an air pump, driven by an eccentric. A spring loaded safety valve on the oil tank keeps the air pressure constant, and this is indicated by a gauge fixed on the tank. There is also a glass gauge to show the oil level in the tank. *O* is the vaporising chamber, provided with a jacket through which the hot exhaust passes. The lamps, *EE*, are used in



FIG. 37.—SECTION OF PRIESTMAN'S OIL ENGINE.

heating the vaporiser initially, and are supplied with oil and air from the oil tank *Y*. The oil tank has a sixway cock, *A*, arranged very simply. When the handle is upright the cock is closed ;

when turned to the left, air and oil are supplied to the starting lamps, *EE* ;

when turned to the right they are sent to the spray-maker, *S*.

The engine cylinder is water-jacketed, the water being circulated either by gravitation from a tank or by a special pump on the engine. At the back of the cylinder are two valves, one being automatic and the other opened by an eccentric.

The upper or automatic valve, *T*, opens on the suction stroke, admitting the mixed air and vapour from the

vaporiser. The lower valve, *T'*, is opened during the exhaust stroke (not during the compression stroke) by an eccentric on a shaft rotating half as fast as the crank shaft. Through this valve the exhaust gases pass to the jacket of the vaporiser. At

FIG. 38.—PRIESTMAN'S OIL ENGINE COUPLED TO A THREE-THROW PUMP.

the back of the engine are shown the bichromate battery and induction coil used for igniting the charge. The circuit is completed at the proper moment by a contact finger on the eccentric rod, which passes between a pair of springs. A screw plug, *K*, in the side of the cylinder contains two porcelain bars, through which the electric wire passes. The electrodes in the cylinder are platinum wires.

In starting the engine the oil tank is put under pressure by the air-pump, and the lamp lighted. When the vaporiser is hot enough, which will be in from eight to twenty-five minutes, according to the size of the engine, the sixway cock is opened to admit oil and air to the vaporiser. The flywheel is then turned, the engine draws in the explosive mixture, compresses it, and starts. The action is that the explosive mixture is drawn in during a suction stroke, compressed in the return stroke, ignited at the moment of full compression, and the working stroke effected by the expansion. The next return stroke drives the products of combustion through the exhaust valve and around the jacket of the vaporising chamber, which is thus heated.

During the compression stroke a small portion of oil condenses inside the cylinder, which it thus perfectly lubricates, rendering all other lubrication unnecessary.

The ignition of the compressed oil vapour is effected by means of a spark between platinum points at *K*, which are connected by two insulated wires with the battery box or igniter. A bichromate cell and induction coil have been found by Messrs. Priestman to be the best practical means of providing the electricity; and they claim that their battery will keep in work from 30 hrs. to 40 hrs. at a cost of under 4*d.*; or, say, 1*d.* per day.

As to the practical results of running this engine, and the cost in comparison with steam or gas, it is stated by the manager of the Teesdale Mineral Co. that an 18 horse-power oil engine supplied to his works for the purpose of driving a grinding mill for barytes has been most satisfactory, and has cost about 2*d.* per horse-power per hour.

In that district the comparative cost of various motors is stated to be as follows :—

62 STEAM BOILERS, STEAM ENGINES, AND OIL ENGINES.

Steam Engine. 20 HP., working 10 hours per day.

„ 10 „ 24 „ „
Cost of coals, £100 per month = 2*d.* per HP. per hour.

Driver's wages, about 5½*d.* per hour.

Lubricating oil, say 3*d.* per hour.

Gas Engine. 6 HP. 400 cubic feet of gas per hour at 4*s.* 8*d.* per 1000 = 3½*d.* per HP. per hour.

Lubricating oil, say 1½*d.* per hour.

Oil Engine. 18 HP.

1 pint of oil per HP. per hour at 8*d.* per gallon = 2*d.* per HP. per hour.

Lubricating oil, 1*d.* per hour.

The oil used is refined petroleum, such as is employed in the domestic lamp, and which is sold everywhere under a variety of names, such as Royal Daylight, Russian, Water White, Scotch Paraffin, etc. The chemicals required for the battery are sulphuric acid, bichromate of potash, and zinc plates. Very small quantities, however, are used. For a run of from 20 hrs. to 30 hrs., 8 oz. of bichromate and 6 oz. of sulphuric acid is ample, while the zinc consumed during that time can be neglected.

For districts where fuel and water are scarce an engine of this class is especially suitable, seeing that petroleum can be procured and transported with ease, the more so as the quantity consumed—a pint per horse-power per hour—is but small.

As with gas engines, so with the oil engine: it is impossible to stop frequently or reverse the motor, so that for hauling or winding purposes a friction clutch must be used. Fig. 38 shows one of these motors applied to a three-throw pump. They are also used for driving dynamos, which is in itself a testimony to the uniformity of the speed which on all of them is controlled by a special governor.

These engines have also been mounted on a truck and attached to a rotary drill, and have also been used for driving air compressors. The advantage in this case is that the engine and compressor can be erected close up to the drills, by which means the long length of piping often required between the drills and the compressing plant is avoided, and a considerable economy thus effected.

CHAPTER IV.

HOISTING MACHINERY.

The Horse Whim—Horse-power Hoister—Portable Winding Plant—Semi-Portable Winding Engine—Single Cylinder Winding Engine with two Drums—Double Cylinder Winding Engine on Girder Frame—Permanent Winding Engines—Geared Hoisting Engine, American Type—Pit Head-gear—Wooden and Iron Frames—The Cage—Keeps or Landing Dogs—Hoisting Plant for Inclined Shafts—Skips—Loading and Unloading Skips.

THE preliminary work at the commencement of the working of a shaft is usually done by means of a wooden jack-roll, or a winch. The depth of the pit and the quantity of rock to be extracted soon, however, become too great for this simple contrivance ; and so, if funds are scarce, and an engine is out of the question, the local carpenter is called in, and a horse-whim is constructed on the lines of that shown in fig. 39, which is the type adopted in Cornwall and Wales.

The construction will be gathered from the drawing, which is to a scale of $\frac{1}{8}$ in. = 1 ft. The diameter of the drum is 12 ft., and that of the horse track 36 ft. ; so that, in order to attain a winding speed of 100 ft. per minute, the horse or horses, if the depth is greater than 50 yds., will have to walk at a rate of $3\frac{1}{2}$ miles per hour. This speed will be found too great for the ancient animals usually employed, and a speed of about 75 ft. per minute in the shaft will be about the average. The framing over the pit carries two pulleys, of from 18 in. to 2 ft. in diameter, the top of each pulley being on a line with the centre of the lower and upper halves of the drum respectively. A hemp rope is employed, and the total load is from 2 to $2\frac{1}{2}$ cwts.

The simplicity of the horse-whim has caused it to be used

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A small hoisting plant for horse-power has been designed, and is largely used in America, for the purpose of overcoming the inconveniences of the old horse-whim, and is illustrated in fig. 40. It consists of a drum, *a*, driven by means of the gearing, *c*. A square wooden pole is fitted into the socket, *b*, to the further end of which a horse is harnessed, and travels in a circular path. The drum is fitted with a powerful strap brake, *d*, and a disconnecting clutch.

The horse travels in one direction only during the hoisting. For lowering the drum is thrown out of gear, and controlled by means of the break.

The winding rope is carried along the ground until clear of the horse, when it passes under a pulley, and then up the pit frame, and over the main winding pulley.

The brake and disconnecting levers are placed close to the pit frame, so as to be conveniently handy to the banksman.

These hoisters are intended for temporary purposes only, but will carry on the sinking operations down to 300 ft. The total load, including the ore and bucket, should not exceed from 800 lb. to 1000 lb., and the speed will vary from 75 ft. to 60 ft. per minute, according to the weight.

PORTABLE WINDING PLANT.—During the preliminary prospecting period, through which a mine must pass before its value is sufficiently established to warrant the erection of permanent machinery, a small portable hoisting plant, such as that shown in fig. 41, is of the greatest utility. This plant has been designed by Messrs. Hornsby and Sons, of Grantham, with the special view of supplying a hauling, hoisting, or power plant on a small scale, which is not only portable, but so constructed as to withstand the rough treatment which it assuredly would receive from unskilled hands.

It consists of a vertical engine, with a vertical cross-tube boiler mounted on a strong wrought-iron girder plate, extended forward so as to carry the winding drum, which is geared to the crank shaft. The engine is fitted with reversing gear. The drum has a

for which purpose a crank is fitted on the end of the drum shaft ; or it can be used for driving a few head of stamps or other machinery, in view of which a turned flywheel is keyed to the engine shaft, from which a belt may be taken to the other machines.

The starting and reversing handles, the clutch lever, and the brake foot lever, are all brought together, so as to be well within the reach of the driver. The pump crank has a stroke of from 1½ ft. to 2½ ft., according to the size of the engine.

These engines are made of the following sizes :—

	Nominal Horse-power.					
	4		6		8	
	ft.	in.	ft.	in.	ft.	in.
Diameter of cylinder	0	6½	0	8½	0	9½
Stroke	0	9	0	10	1	3
Revolutions per minute	165		150		135	
Diameter of drum	2	6	3	0	3	0
Depth of cheek	0	7	0	7½	0	7½
Diameter of drum over cheeks ...	3	8	4	3	4	3
Width of drums	1	7	1	9	2	0
Weight lifted at 250 ft. per minute ...	8 cwt.		12 cwt.		16 cwt.	

SEMI-PORTABLE WINDING ENGINES.—As the chances of failure in metalliferous mining are generally supposed to be greater than those encountered in collieries, and also as the weight to be raised per day is usually less in the former than in the latter case, it often happens that the hoisting machinery is of a more temporary character than that put down for raising coal.

The necessity also of providing such machinery as can be readily transported over mountainous country has led to the introduction and extended use of winding engines of the semi-portable type, such as those illustrated in figs. 42 and 43, and manufactured by Messrs. Robey, of Lincoln, in sizes of from 4 to 200 actual horse-power.

The boiler is of the locomotive multitubular type, with an iron chimney, which receives the exhaust from the engines, thus creating a powerful draught, and so admitting the use of inferior fuel. It is mounted with all the usual fittings, and the driving handles,

brake levers, and clutches are all so arranged as to allow of the engine being attended to by one man only.

FIG. 42.—ROBEY SEMI-PORTABLE WINDING ENGINE (SIDE VIEW).

FIG. 43.—ROBEY SEMI-PORTABLE WINDING ENGINE (FRONT VIEW).

Formerly the engines were mounted on top of the boiler, but this type is now obsolete, and they are placed underneath, being mounted on a cast-iron bed plate, which has also suitable bearings

for receiving the pumping and winding shafts, brake shafts, and levers, so that the boiler is relieved from all strain due to the engine. The crank-shaft carries a heavy flywheel at one end, and a pinion wheel at the other, which gears into the spurwheel on the drum shaft. The weight of the full boiler greatly helps to steady the engine, and consequently reduces the amount of foundations necessary.

The cylinders are steam jacketed, fitted with link motion reversing gear, and are so arranged that a portion of the exhaust is directed into the feed-water tank, which is in the base plate underneath the cylinders. It is claimed that, owing to the many improvements made in this engine, an economy of fuel of from 10 to 50 per cent. is effected over the old type.

As the boiler fits over the engine, and is not permanently connected with it, the engine can be obtained separately, and driven from any existing boilers; or the boiler and engine can be mounted apart in places where it is inconvenient to have them combined on the same base plate, as in fig. 53.

A crank is fixed at the end of the drum shaft, to which the pump rods may be attached, and the drums are each supplied with a disconnecting clutch, so that they may be used separately, or entirely disconnected when the engine is required for pumping only.

These engines are well adapted for raising the heavy loads customary in metalliferous mines, at a comparatively low rate of speed—say, of from 400 ft. to 500 ft. per minute.

They are much steadier than the older type with the engines mounted on the boiler, and if care is taken to give them a firm foundation, they will fulfil all the purposes of a permanent "plant," which may or may not be substituted when the production and development of the mine warrant the outlay.

In order to get over the difficulty of a brick or stone foundation in those parts of the world where building materials are scarce, Messrs. Robey have designed an engine which will practically work without foundation. The engine, boiler, and gearing are the same as those already described, but are mounted on a wrought-iron tank a yard or more in depth.

In fixing the engine, it is only necessary to make an excavation

HOISTING MACHINERY.

round of suitable size to receive the wrought-iron tank and then be filled with earth or sand, and so form a firm foundation.

transport the loose fittings of the engine are packed in the which is a convenient mode of storage.

moving the winding gear, and adding a belt pulley in the pinion, this class of engine is converted into one for driving a concentration mill, and is indeed largely that purpose. For milling purposes, however, it is more separate the engine and boiler for convenience' sake in and construction of the building.

on now to winding engines of a more permanent type, in fig. 44 the photograph of a very simple form of winding consisting of a single cylinder, horizontal, fixed engine, two drums, both of them loose on the drum shaft, but of being thrown in or out of gear by means of the and levers. This plan of winding or hauling engine sed for working two pits or inclines at the same time, drum can be employed independently by putting it in gear, and controlling it by its own brake. A pump also fitted to the end of the drum shaft, so that the ay be used for winding and pumping either at the same separately.

engines are commonly made in the following sizes, and le of doing the work mentioned below :—

Size	1	2	3	4	5	6
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
f drum barrel	2 6	3 0	3 6	4 0	4 6	5 0
of drum over						
... ..	3 10	4 8	5 2	5 8	6 6	7 0
icks	0 8	0 10	0 10	0 10	1 0	1 0
drum, plans						
nd 2	1 8	2 0	2 2	2 2	2 4	2 4
ch drum, plan						
nd each divi-						
1 1A and 2A ...	0 10	1 0	1 1	1 1	1 2	1 2
HP. of steam						
suitable for use						
above winding						
ly	4 to 10	6 to 16	12 to 20	16 to 25	20 to 30	30 to 40

FIG. 44.—SINGLE CYLINDER WINDING AND PUMPING ENGINE.

HOISTING MACHINERY.

each nominal HP. of the engine used, the load lifted vertically will be 2 cwt. at a speed of 250 to 300 ft. per minute.

Lifted up an incline 1 in 5 ... 8 cwt. at a speed of 250 to 300 ft. per min.

" " 1 " 10 ... 16 " " " "

" " 1 " 50 ... 80 " " " "

" " 1 " 100 ... 160 " " " "

The gearing can, however, be arranged, if desired, to lift or haul heavier loads at a slower speed, or lighter loads at a quicker speed.

A compact light form of winding or hauling engine for comparatively small power is shown in fig. 45.

The engines and drum are mounted on a wrought-iron girder, the engine shaft being on the further side of the drum, so that the drums are completely within the engine frame; saving space, but preventing the use of a pump crank drum shaft.

These engines are supplied either with two separate drums fitted with catches and brakes, or with one drum keyed to the shaft, giving a division plate in the middle. They are somewhat different from the ordinary form of winding engine, and are largely adapted either for hauling purposes at large mines or for winding at small ones.

The following are their general dimensions:—

	Nominal Horse-power.									
	10		16		20		25		30	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Radius of cylinder ...	0	7½	0	9½	0	10½	0	11½	1	0½
" " " " " " " " " " " "	12		16		20		20		22	
Radius of drum ...	3	6	3	6	4	6	4	6	5	0
Radius of drum over cheeks ...	5	2	5	2	6	6	6	6	7	0
Radius of drum cheeks ...	10		10		12		12		12	
Radius of each drum division	13		13		14		14		15	

PERMANENT WINDING ENGINES.—Messrs. Hornsby, of Grantham, are the makers of a form of winding engine shown in fig. 46, which is much approved of in South Africa and other mining districts. The engine has double cylinders, with outside cranks, the crank shaft being geared to the drum shaft, which carries a pair of drums. Each drum is loose on the shaft, and is capable of

being clutched to it, and is provided with a brake. There is also a brake on the flywheel.

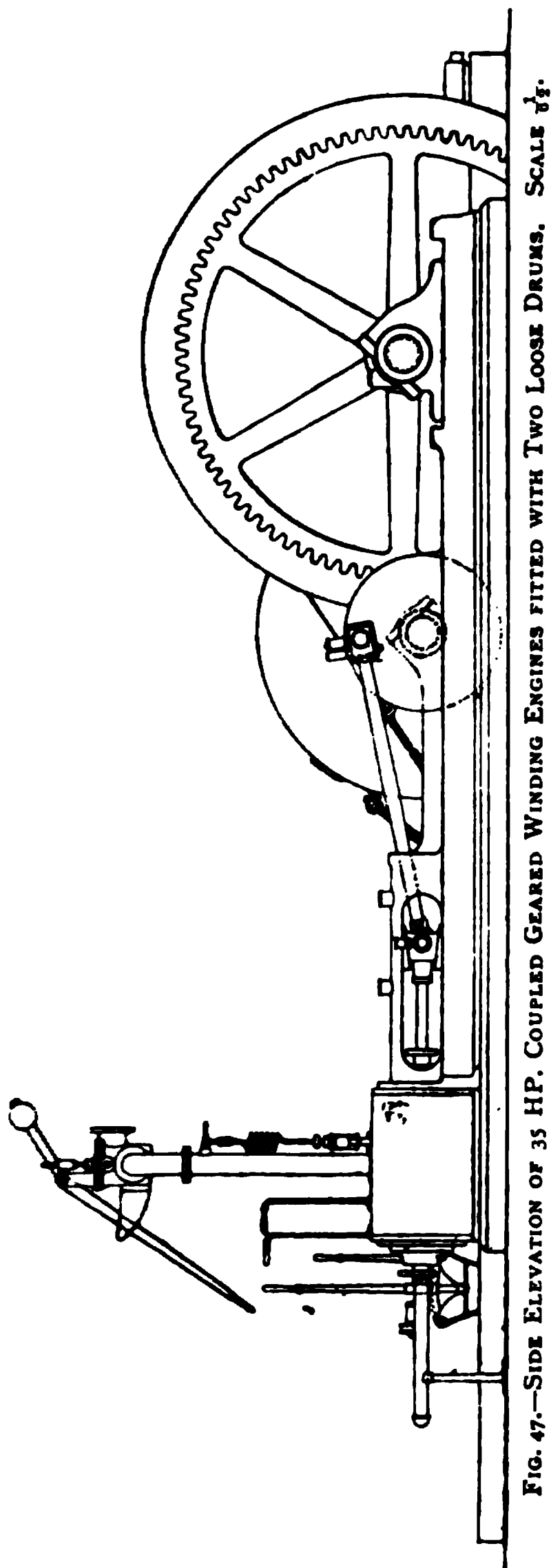
The whole of the brake and clutch levers, starting and reversing handles, are all brought to the back, so as to be readily handled by one man. The illustrations are from drawings to scale, and show clearly the details of the whole arrangement. Engines of this type require solid foundations of masonry, and as their use would imply that the mineral wealth of the undertaking was fully established, they should be covered in with a substantial engine house, from which all loafers should be rigorously excluded.

FIG. 45.—DOUBLE CYLINDER WINDING ENGINE ON IRON GIRDER FRAME.

Some engine drivers take a great pride in keeping the engine house clean and tidy. Strips of carpet are laid on the tiled floor, and flowers adorn the windows, while the luckless stranger who ventures in with dirty boots is promptly ejected.

GEARED HOISTING ENGINE, AMERICAN TYPE.—The hoisting engine shown in connection with the pit head frame for an inclined shaft in fig. 54, may be taken as typical of this class of machine as made in America. In the illustration the two flat rope drums are shown in use; for round ropes the engine would of necessity be wider, but the general arrangements would remain the same.

FIG. 46.—35 HP. COUPLED GEARED WINDING ENGINE FITTED WITH TWO LOOSE DRUMS. SCALE $\frac{1}{4}$ ".



An enlarged view of these engines is given in fig. 48, which is the plan, and fig. 49 the section. There are two slide-valve engines, with link motion reversing gear attached, nearly at right angles to the same crank shaft, on which is a large pinion wheel, which gears into the spurwheel keyed to the centre of the drum shaft.

The crank shaft is supported in the centre by means of a bearing on each side of the pinion, in addition to those on the engine frame. The drum shaft bearing boxes are made in halves, lined with composition metal, and fitted into planed seats in the cast-iron extension pieces of the engine frame, and are secured by substantial caps bolted to the frame.

The drums are independent, run loose on the shaft, and are provided with composition metal bushings, held in place by bolts, admitting of their being readily replaced when worn. The hubs of the drums have a four-toe

engineer or attendant stands at one reel or the other, and foot brake must be used in each instance.

For convenience of attaching all levers to one substantial casting, a mounting plate is provided between the cylinders, and

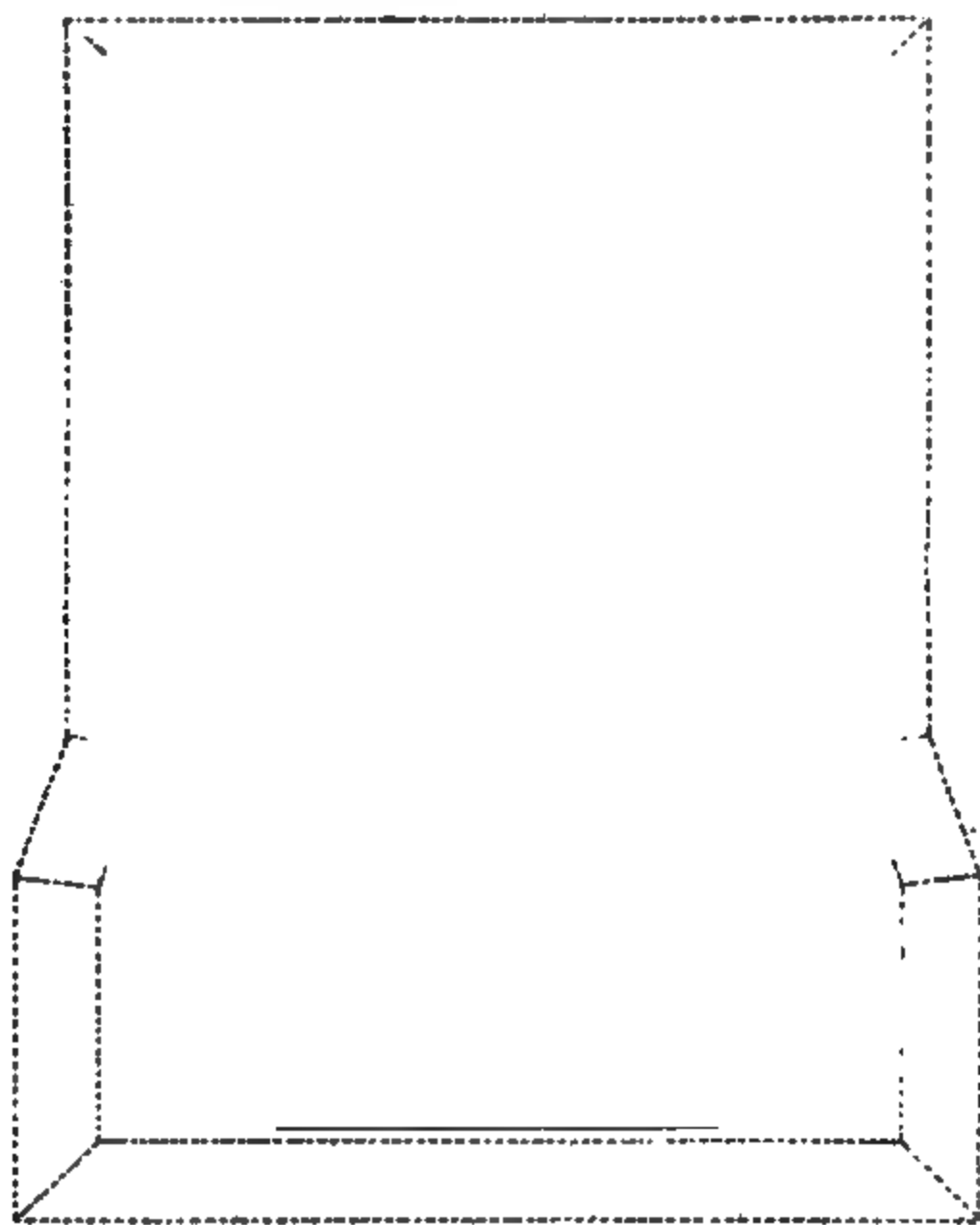


FIG. 49.- PLAN OF GEARED HOISTING ENGINE, AMERICAN PATTERN, FLAT ROPE DRUMS.

is bolted to the foundation at a point where all the levers, including the stop valve lever, lever to link with quadrants and standards, rocker shaft and link levers, post brake levers with hand wheels, racks and pinions mounted on stands, clutch levers

HOISTING MACHINERY.

not levers for crank brakes can be reached by the attendant at effort.

indicator is attached to each drum separately, and the top of each is well in view of the driver, so that he can tell exact position of each step or cage in the shaft.

This class of engine is made in two sizes, one with double cylinders, 10 in. diam. \times 16 in. stroke, with drums for a $2\frac{1}{2}$ in. or $2\frac{3}{4}$ in. flat wire rope, and designed for vertical depths of 700 to 800 ft., and the other with double cylinders, 12 in. diam. \times 18 in. stroke, for a 3 in. or $3\frac{1}{2}$ in. flat wire rope, for vertical lifts of 1000 ft.

The use of the Pelton waterwheel for hoisting purposes will be described on page 17, and of electricity for the same purpose in Chapter XXVII.

-HEAD GEAR.—The pit-head gear may be constructed of iron or of steel, in which latter case it can be made extremely strong for transport, and at the same time enormously strong.

When made of wood, pitchpine is usually employed, the construction being shown in figs. 50 and 53. The frame should be as high as possible, as its height represents the margin of safety against the engineman against overwinding. With high speed acting engines, the lift may be as much as 50 ft. for each stroke of the engine, but with the geared engines generally used in talliferous mining, the lift per stroke is correspondingly less.

The height varies between 30 ft. and 70 ft., and is greater for iron pit head frames than with wood, owing to the greater strength and stability with which high structures can be made in the former case than in the other.

The uprights, two or four in number, forming the frame, and the backstays or inclined pieces, are the main features of the work, and must be so arranged as to best resist the vertical strain and the backward pull towards the engine house. The main timbers are from 12 in. to 16 in. square, strongly jointed, and bound together over the more important joints with wrought-iron straps. The double tenon joint, secured by an iron bolt passing through each tenon, is the most suitable; and careful workmanship must be exacted throughout, so that the joints may be accurately and flush. Before being finally bound together

each joint must be painted over with red-lead, and the vertical legs, as well as the backstays, should fit into a cast-iron footing resting on a concrete foundation.

The angle of the backstays should be as nearly as possible that of the rope, and this latter should not make a less angle than 45° over the pulleys, in order to lessen the wear and tear of the rope. The diameter of the pulleys should be as great as possible,

FIG. 50.—PIT-HEAD GEAR. WOOD.

and varies from 10 ft. to 20 ft. A good rule is to make them of the same diameter as the winding drum. They are now almost universally made with a cast-iron boss and rim, and wrought-iron spokes.

The groove is V-shaped or flat according to whether round or flat ropes are used. The pulleys are keyed on to wrought-iron shafts, and are carried in strong pillow blocks, with heavy gun-metal bearings and adjustable roll plates.

Both the wooden and the iron pit heads, such as that shown in

n, and handrail, so
the bearings and

ineral are run on to
2, for which purpose
gauge as the trucks ;
and the load is thus
hoisted to the sur-
face, with a mini-
mum amount of
handling. The cage
itself is strongly
built of Swedish
iron or steel. It
runs between a pair
of wooden or wire
rope guides, for
which purpose it is
provided with slides,
b b. If wire ropes
are used as guides,
a clearance of from
12 in. to 18 in.
must be left, so that
the cages in passing
each other may run
no risk of collision.
With rigid wooden
guides this may be
le are provided with
hold the guide rods

y catches, *d d*, which
ght of the cage hangs
st them immediately
aking or otherwise.
t the men from being
d is hinged to open

towards the centre, so that it may be thrown back out of the way and admit of long timbers being carried on end.

If required, the cage may be double decked, so as to carry two trucks, one below the other. For the comparatively light loads contained in the tram waggons of a colliery, the cages are made to carry two waggons on each deck, and so lift four at a time. The enormous quantities of coal raised per day could not otherwise be dealt with; but the weight of a truck of ore does not permit of its being handled in such a wholesale manner.

On arriving at the surface, or at one of the various levels in a mine, the cage is supported on the "keeps," *ff*, shown in fig. 52. The cage in passing opens these, and then is dropped on the top of them, being thus brought to the exact level of the rails on the pit bank. When the cage is raised again the lever, *g*, is drawn back, and the keeps are thus held clear, while the cage passes through and down the pit.

The winding rope is attached to the cage by a short length of chain shackle, and is usually provided with a safety detaching hook, for the prevention of overwinding. This hook is so arranged that when it passes through a funnel-shaped cast-iron cylinder fixed on the pit head, the winding rope is detached, the cage held suspended, and an accident thus avoided.

FIG. 52.—SINGLE DECK CAGE, WITH LANDING DOGS.

A good and complete arrangement of boilers, winding and pumping engines, and pit head gear, is shown in fig. 53, which also illustrates the construction of a double pit-head gear in wood

FIG. 53.—ARRANGEMENT OF WINDING GEAR AT PIT-HEAD.



Where the quantity of water is small the pumps can be driven by the winding engine, or tanks be fitted into the cages for winding out the water.

PIT-HEAD AND HOISTING PLANT FOR INCLINED SHAFTS.—The hoisting plant described for vertical shafts is not adapted to those which follow the lode downwards on the line of its dip. For shafts of this description an arrangement such as that illustrated in fig. 54 is the most suitable.

The skip, with its load of mineral, runs on longitudinal wooden

FIG. 54.—COMPLETE HOISTING PLANT FOR INCLINED SHAFT.

sleepers, the upper surface of which is covered with a slip of iron in order to resist the wear. The skip itself is of iron or sheet steel of the form illustrated in fig. 55. The tread of the leading wheels is half the width of that of the trailing, and the rope is attached to an iron hoop hinged at the back of the skip. At the surface, or at any suitable point above it for tipping purposes, there is a break in the sleepers, which decreases them by half their width, the result of which is that the leading wheels, being narrower in the tread, follow this break on an almost horizontal line, while the trailing wheels keep to the original sleepers. The

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tipped into an ore bin, where it is allowed to accumulate until the bin is full. The mouth of the bin is closed with a shutter, and below it there is a small platform on which a couple of men may stand for the purpose of loading the skip. When the ore is to be wound the skip is stopped at the level of the platform, its weight resting on an iron framework drawn across the shaft, as shown in the illustration. By this means the weight is taken off the rope and the skip held in exactly the right position. Loading is then commenced, the big lumps being thrown in by hand and the fine shovelled in until the bin is empty, when the fillers withdraw the iron framing, and the skip can then descend to

FIG. 56.—LOADING ARRANGEMENT IN AN INCLINED SHAFT.

a lower level and be filled with ore from another bin.

A signal wire is fitted in the shaft, as usual, so that the fillers can communicate with the engine-man. The position of the various loading platforms is marked on the indicator in the engine-room, so that the engine-man knows exactly the conditions under which he is working.

CHAPTER V.

DRAINAGE OF MINES AND PUMPING MACHINERY.

g Barrels—Pumping Arrangements—Action of Pump—Plunger
 Pump Rods—Balance Bobs—Details of Pumping Lift—Quantity
 delivered at Each Stroke—History of Development of the
 Pumping Engine—Watts—Hornblower—Woolf—Duty of En-
 gine—Cornish Engine—The Cataract Governor—Cost of Cornish
 Engine—Husband's Safety Governor—The Geared Engine—The Direct
 Acting Compound Pumping Engine (Surface)—Direct Acting Steam
 Engine—The Worthington Pump—The Duplex Arrangement—The High
 Pressure Indicator Cards of Worthington Pumps—Pumping
 Worthington Pump at Osborne Hollow.

DRAINAGE OF MINES.—The best and most economical
 method of draining a mine is doubtless by means of an adit level, but
 this is not always possible. In some cases, where
 the veins of mines are to be unwatered, it will pay to go to
 the expense in driving long adits, as in the case of the
 adit to the Comstock lode and the Halkyn Mountain
 drainage scheme, Flintshire.

In some cases, however, the adit can only be driven to tap the
 veins at a comparatively shallow depth, and in these cases, as
 where no adit can be constructed owing to the
 irregularity of the surface, some mechanical means must be
 resorted to in order to raise the water from the bottom of the shaft
 to the level of the adit or to the surface, as the case may be.
 If the quantity of water is but very small it can be raised by
 buckets, cips, barrels or bows; but usually it is found more
 economical to put in a set of pumps, as with only 20 gallons a
 minute removed it would take more than six hours' winding,
 whereas at a time and twenty tons an hour, to clear the

Where the quantity is small it is allowed to accumulate in a sump or reservoir, from which it is wound during the night or at other convenient times. For this purpose a water barrel is attached to the end of the winding rope, or a water tank slipped into the cage.

The usual form of a water tank is shown at *c*, in fig. 57, and may be made to hold up to 500 gallons. At the bottom is a valve, which lifts when the barrel strikes the water, and allows it to fill. When it is raised to the surface a platform is pushed over the mouth of the shaft and the barrel lowered on to it. The spindle of the valve strikes the platform, raises the valve, and

FIG. 57.—A. Kibble for Winding Ore. B. Tipping Kibble or Bowk. C. Barrel for Winding Water with Valve at Bottom.

automatically empties the barrel. The water is conducted away through suitable channels.

As soon as a mine obtains considerable proportions, and when the permanent shafts are sunk, the simple method of winding out the water will no longer suffice to keep the workings dry, so that a permanent pumping plant becomes a necessity. For comparatively shallow depths it is usual to employ a bucket lift only, but for greater depths a forcing lift is used in addition, the bucket lift being placed near the bottom of the shaft. This is used to lift the water to a certain height, from which again it is forced by a plunger or forcing lift.

19.—ARRANGEMENT OF PUMPS IN A MINE SHAFT.

Piece. 2. Platform and Bearers across Shaft at Mouth of
live Door. 4. Working Barrel. 5. Bucket Door. 6. Wooden
case or Wind Bore of Plunger or Forcing Lift. 8. Iron Plunger
Case. 10, 11. Clack or Valve Doors. 12. Set-off or Junction of
Plunger Pump Rod. 13. Pump Rods rising to Junction with
Main Working Beam. 15. Engine House. A.A. Plunger Lift.
2. Shaft.

The ordinary pumping arrangements are shown in figs. 58 and 59, in which fig. 58 represents the pumps in the shaft, and fig. 59 is a continuation of the same at right angles to fig. 58 up to the surface. For the sake of clearness the ladderways are left out, but for great depths one or more balance bobs, shown in fig. 78, must be added to take up the weight of the rods which, in deep shafts with powerful pumps, amounts to as much as 60 tons.

It will be seen that the water is first of all drawn up from the sump by the suction pipe 1, by means of the lower or bucket lift, the bucket and valves being in the working barrel, 1; the amount of suction should not exceed from 20 to 24 ft.; passing the valves the water is then lifted by the bucket up to the first water lodge, a height of about 80 to 100 yds., the pump rods working inside the lift.

It must be borne in mind that the action of a pump depends upon the atmospheric pressure, which is equal to a column of water 34 ft. high at sea level. When the bucket is raised in the working barrel of a pump it forms a vacuum behind it, more or less perfect, and into this vacuum the atmospheric pressure will drive the water and cause it to follow the bucket upwards for a distance not exceeding 34 ft. But there are various losses and defects inherent to the practice of pumping, so that the full theoretical effect cannot be obtained. The bucket, therefore, should never be raised to a height exceeding say 30 ft. from the surface of the water in the pit. As a rule, the bottom of the working barrel is not more than 9 or 12 ft. above the wind bore or blast piece, and as the stroke of the bucket or plunger rarely exceeds 12 ft., the total suction is under 24 feet, so that the pump is kept at work under the most favourable conditions and the bucket should be effective for the full length of its stroke.

The plunger or forcing lift commences at the first water lodge, the lifting rods of the bucket lift being here connected to the forcing rods as shown at 12 in fig. 58.

The rods now no longer work inside the pump and so contract its area, but outside, being guided at intervals in the shaft and forcing upwards by their weight, acting through the plunger at their foot, the column of water in the pipes.

The plunger works through a stuffing box into a plunger case

AINAGE OF MINES AND PUMPING MACHINERY.

l cast iron, and at every down stroke forces a column of
qual to its own bulk through the valves into the pump

umber of lifts in a shaft depends upon its depth; as a
re is one for every 100 yds.

ump rods, which play a most important part, are made
ht square balks of wood in sections of from 30 to 40 ft.
ned together by scarfed joints and secured by wrought-
tes bolted through the timber. Sometimes these plates
ed on two sides only, but often a plate is placed on each
our sides.

plungers of the pumps are fastened to the main line of
ds by means of a set-off, as shown in fig. 66, at the several
In perpendicular shafts the rods work in guides in order
them in a straight line, and at these points they are cased
d wood and greased in order to lessen the friction. In
shafts the rods run on rollers, but in other respects the
ents are the same.

ize of the pump rods or spears depends upon the work
from them, and roughly are the square of the diameter
mp plunger in section. The following table will give the
mate sizes of the rods and connections :—

APPROPRIATE SIZES AND PROPORTIONS OF PUMP RODS (*Carr*)

Spears or Rods.	Spear Plates and Bolts.				
	Scantling Square.	Length.	Breadth.	Thickness in the Middle.	Thickness at the Ends.
	Inches.	Feet.	Inches.	Inches.	Inches.
3	6	2½	¾	1½	1½
3½	6½	2½	¾	1½	1½
4	7	3	¾	1½	1½
4½	7½	3½	¾	1½	1½
5	8	3½	¾	1½	1½
5½	8½	4	¾	1½	1½
6	9	4	¾	1½	1½
6½	9½	4½	¾	1½	1½
7	10	4½	¾	1½	1½
7½	10½	4½	¾	1½	1½

The weight of the rods is usually in excess of that required to lift the water and overcome friction, and the excess must be relieved by means of a balance bob, fig. 78, which consists of a beam of iron or timber of from 20 ft. to 30 ft. long, turning upon an iron axle, and loaded at the one end with a box filled with stones or scrap iron.

The excess weight of the rods is thus balanced, but with the single action Cornish pumping engine described on p. 98 it must be remembered that as the down stroke of the rods causes the up stroke of the engine, there must always be left a sufficient excess of weight in order to effect this. When, however, a double-acting engine is employed, such as the compound horizontal Corliss engine shown in fig. 78, where the force of the steam is used equally on both sides of the piston, the more nearly the weight of the water in the rising mains corresponds to the weight of the rods the better, so that the engine may have an equal amount of work to do during both portions of the stroke, and may run with greater regularity.

FIG. 60.—SLID-
ING WIND BORE
OR SUCTION
PIPE.

FIG. 61.—
WORKING
BARREL.

FIG. 62.—H-PIECE AND DOOR.

FIG. 63.—CLACK PIECE AND DOOR.

AGE OF MINES AND PUMPING MACHINERY.

us parts of a pumping lift are shown in figs. 60 to 69.
a sliding wind bore or suction pipe used in sinking in
with a bucket lift. It is made of extra strength in

FIG. 69.



FIG. 64.



FIG. 66.

FIG. 65.



FIG. 67.

FIG. 70.—PLUNGER PUMP,
WITH PLUNGER, VALVES,
AND WIND BORE.

t the shock of the stones during blasting operations.
is left, which is closed by a wooden plug, and is
ing the inside of the other bores.

the working barrel of a bucket lift, accurately bored

out so that the bucket may fit perfectly. The ends are bored slightly conical, in order to facilitate the entry of the bucket. The pipes for the lift are of the same form, with the exception that they are not bored out but left rough. The flanges are turned so that the joints may be perfect.

Fig. 62 is the H-piece and door for a plunger set with the clack and a portion of the plunger or pole case attached by a branch.

Fig. 63 is a clack piece and door for either a plunger or bucket lift, and is strengthened by means of numerous ribs in order to resist the shock and pressure of deep lifts.

Fig. 64 is a bucket and sword to suit a Y-rod, as shown in fig. 65, to which it is attached by means of the clasp joint. The bucket valves are made of leather, strengthened with iron; and the bucket packing is also of leather, held in place by means of an iron hoop.

Fig. 66 is a clack or valve for a plunger or bucket lift. The valve is of leather, strengthened with iron plates. For bucket lifts, when it is required to draw the clack up inside the pipes, the form shown in fig. 67 is used.

Fig. 68 shows a set of strapping plates and brasses for connecting the wooden rods to the engine or to the tee-bob.

Fig. 69 is a pair of ordinary strapping plates for making the joints in the wooden pump rods.

Fig. 70 represents a plunger pump fitted up with the plunger, H-piece, and valves, together with the wind bore.

The plunger is connected to the rods by means of a Y-piece, as shown in fig. 65, but in the illustration only the lower part of the piece is shown.

The pump lift is secured in the shaft on massive timber bearers, the rods of the plunger lift are stayed at intervals, and at those points where they pass through guides a sheathing of hard wood is provided in order to receive the wear and tear which otherwise would soon cut the rod in two. One great advantage of the Cornish pumping lift is that the engines are on the surface above the mine and are accordingly always accessible for repairs. The efficiency of the lift depends upon the state of the valves, bucket, and plunger packing; but in good working order the delivery may be ascertained from the following table which shows at a glance the quantity

TABLE SHOWING QUANTITY OF WATER, IN IMPERIAL GALLONS,
DELIVERED BY A PUMP AT EACH STROKE OF THE ENGINE (*continued*).

Diameter of Pump in Inches.	LENGTH OF STROKE.					
	4 ft. 6 in.	5 ft.	5 ft. 6 in.	6 ft.	6 ft. 6 in.	7 ft.
10	15'30	17'00	18'70	20'40	22'10	23'80
11	18'50	20'55	22'62	24'67	26'72	28'78
12	22'02	24'47	26'92	29'37	31'81	34'26
13	25'85	28'72	31'59	34'47	37'33	40'21
14	29'97	33'30	36'64	39'97	43'29	46'63
15	34'41	38'23	42'06	45'89	49'70	53'53
16	39'16	43'51	47'86	52'22	56'57	60'92
17	44'21	49'12	54'03	58'95	63'85	68'77
18	49'55	55'06	60'57	66'08	71'58	77'09
19	55'21	61'35	67'48	73'62	79'75	85'89
20	61'18	67'98	74'78	81'58	88'38	95'18
21	67'45	74'95	82'44	89'94	97'43	104'93
22	74'03	82'26	90'49	98'72	106'95	115'17
23	80'91	89'90	98'90	107'89	116'87	125'87
24	88'11	97'90	107'69	117'48	127'27	137'06
25	95'60	106'22	116'85	127'47	138'08	148'71
26	103'41	114'90	126'39	137'88	149'37	160'86
27	111'51	123'90	136'30	148'69	161'07	173'47
28	119'93	133'25	146'58	159'91	173'23	186'56
29	128'65	142'95	157'24	171'54	185'83	200'13
30	137'67	152'97	168'27	183'57	198'86	214'16
31	147'00	163'33	179'67	196'01	212'33	228'67
32	156'64	174'05	191'45	208'86	226'26	243'67
33	166'59	185'10	203'61	222'12	240'63	259'14
34	176'83	196'48	216'13	235'79	255'43	275'08
35	187'39	208'21	229'03	249'86	270'68	291'50
36	198'24	220'27	242'30	264'33	286'35	308'38
	7 ft. 6 in.	8 ft.	8 ft. 6 in.	9 ft.	9 ft. 6 in.	10 ft.
3	2'28	2'45	2'59	2'74	2'89	3'06
4	4'07	4'35	4'61	4'89	5'16	5'44
5	6'37	6'80	7'22	7'65	8'07	8'50
6	9'17	9'79	10'39	11'00	11'61	12'23
7	12'48	13'32	14'15	14'98	15'81	16'65
8	16'31	17'40	18'48	19'57	20'65	21'75
9	20'64	22'03	23'39	24'77	26'14	27'53
10	25'50	27'20	28'90	30'60	32'30	34'00
11	30'84	32'90	34'95	37'00	39'05	41'12
12	36'71	39'16	41'60	44'05	46'49	48'95
13	43'08	45'96	48'83	51'70	54'57	57'45
14	49'96	53'30	56'62	59'95	63'27	66'62
15	57'35	61'19	65'00	68'82	72'64	76'48
16	65'27	69'62	73'97	78'32	82'67	87'02

OF MINES AND PUMPING MACHINERY.

G QUANTITY OF WATER, IN IMPERIAL GALLONS,
PUMP AT EACH STROKE OF THE ENGINE (*continued*).

LENGTH OF STROKE				
8 ft.	8 ft. 6 in.	9 ft.	9 ft. 6 in.	10 ft.
78'60	83'51	88'42	93'33	98'25
88'11	93'60	99'11	104'61	110'13
98'17	104'29	110'43	116'56	122'71
108'78	115'57	122'37	129'16	135'97
119'93	127'41	134'91	142'40	149'91
131'63	139'84	148'07	156'29	164'53
143'86	152'84	161'83	170'81	179'82
156'65	166'43	176'22	186'01	195'81
169'97	180'58	191'22	201'82	212'46
183'85	195'33	206'82	218'31	229'81
198'26	210'64	223'03	235'41	247'82
213'22	226'54	239'86	253'18	266'52
228'72	243'01	257'31	271'16	285'90
244'76	260'05	275'35	290'64	305'95
261'35	277'67	294'00	310'33	326'68
278'48	295'88	313'29	330'69	348'10
296'16	314'67	333'18	351'69	370'20
314'39	334'02	353'67	373'31	392'98
333'15	353'96	374'78	395'60	416'43
352'44	374'46	396'49	418'51	440'55

ver which actuates the pump rods may be either and we will now proceed to investigate briefly tion and development of the steam engine as ing the water from mines.

G MACHINERY.—Thomas Newcomen and John outh, Devonshire, are supposed to have been the st steam or atmospheric engine that successfully or the drainage of mines. They erected one of olverhampton in 1712, which is reported to have lly. In the year 1737 we find an engine of ruction working a succession of 7-in. lifts, having t the rate of 15 strokes per minute; each lift was h, so 11 of them were required to raise the water ich was 267 ft. deep.

i engine was greatly improved by Smeaton, who is improved engines in the Chasewater Mine,

near Truro, Cornwall, in 1775. This engine had a cylinder 72 in. diameter, with 9 ft. stroke, and it developed about 76 horse-power. It is interesting to note some of the dimensions of Smeaton's engine. The cylinder was $10\frac{1}{2}$ ft. long, and weighed 4 tons 16 cwt. ; the piston was in the form of a flat circular disk, 66 in. in diameter by $1\frac{1}{2}$ in. thick, the edge of the disk being raised to form a vertical rim 5 in. high ; boards were bolted on beneath the iron disk to form the actual steam-tight packing. This engine operated 3 columns of pumps, $16\frac{3}{4}$ in. diameter and 34 yds. in length, a total lift of 102 yds. The water load was estimated at 14 tons, the load on the piston being about $7\frac{3}{4}$ lb. per square inch.

In 1769 Watts had completed and patented his great discovery of a separate condenser, which was destined to revolutionise the steam engine. The Chasewater engine, though the most powerful machine in existence when erected on that mine, was also the last effort of a system then passing away—the final effort on the part of the atmospheric engine. The Chasewater engine was altered and remodelled by Watt a few years later. These alterations brought up the duty of the engine to about 20,000,000 foot-pounds, and created, as it were, a prototype of the Cornish pumping engine, which was so rapidly developed under the guidance of Hornblower, Woolf, and Trevithick, the greatest of Cornish engineers.

In 1781 Hornblower constructed and patented a compound engine having two cylinders of different sizes, steam being first admitted into the small cylinder, then, passing over into the large cylinder, did work in each. The compound engine was revived by Woolf in 1804. No doubt Hornblower and Woolf saw clearly the advantage to be gained in expanding the steam in two cylinders instead of in one, as the sum of the forces exerted by the two pistons in the compound engine varies less than the force exerted by the piston of the single-cylinder engine for the same amount of expansion. It is doubtful, however, if they understood the more important merit of the compound system, which lies in the fact that by dividing the whole range of expansion into two parts, the cylinders were kept at a more uniform temperature relative to the expanding steam, thus limiting the waste which results from the heating and cooling of the metal by its alternate contact with

he

of

Watt; and, indeed, it is but carrying out one of the laws laid down by Watt himself, "that the cylinder should be kept as hot as the steam that enters it."

Woolf introduced his compound engine extensively about the year 1814 as a pumping engine in the Cornish mines, but on account of its complicated mechanism, and extra first cost, it did not successfully compete with the high-pressure single-cylinder engine of Trevithick, which had the advantage of simplicity of construction—a very important point in those early days of mechanical engineering; therefore Woolf's engine fell into comparative disuse, and the single-cylinder type took a form which, under the name of the Cornish pumping engine, has long been famous for its economy of fuel.

Woolf was the first who succeeded in making a wrought-iron boiler tight for high-pressure steam. This was accomplished in 1817, and gave a considerable impetus to the expansive working of steam in the engine. Woolf's compound engine at Wheal Abrahams in 1815 did 52 million foot-pounds. His single-cylinder engine at Consols in 1827 is reported to have exceeded 64 millions. Thus we see Woolf found the Cornish engine with an average duty of 20 millions, and left it with over 60 millions.

When complimented on his great success in this direction, he is reported to have stated that some of the boys he had in training would make the Cornish engine do 100 million duty; and it appears they did succeed in reaching, and even exceeding, this high standard of efficiency, if we accept the accuracy with which these duty tests were conducted. That many and serious errors crept into the trials and reports few will deny, while many competent investigators are led to the conclusion that either exaggeration has entered into many of the phenomenal reports, or that the actual trial of the engine was for too short a period to be reliable. Some of the high duty reports were based on two to three hours' test. On the other hand, it is pointed out that the engines designed by the pupils and successors of Woolf were erected on shallow mines, had extremely light loads, resulting in early cut-off and high expansion; in such cases the duty would, no doubt, reach a high figure.

The celebrated Fowey Consols engine, reported at 125 million

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1835 (say $1\frac{3}{4}$ lb. coal per horse-power per hour) is still as almost unapproachable. This engine had an 80 in. \times $10\frac{1}{2}$ ft. stroke, and only developed 62 horse-power when discharging its remarkable duty.

CORNISH PUMPING ENGINE.—The following description of the modern form of the Cornish pumping engine is chiefly from André's "Treatise on Coal Mining."* The cylinder, 80 in. in diameter, with a 10-ft. piston stroke. It is provided



FIG. 72.—ENLARGED VIEW OF THE GOVERNOR VALVE.

cast-iron steam jacket, connected with the boilers by the pipe, H, so that the water of condensation returns by it. Where the boilers, in unavoidable circumstances, are above the cylinder, the pipe to the steam jacket cannot serve as a return for condensed water, and provision must be made for freeing the jacket from condensed water by means of a steam trap. The steam jacket

is also described in the "Colliery Manager's Handbook," by Caleb Pamely (Crosby and Son).

is encased in wood ; the annular space between the two is filled with some non-conducting medium, such as sawdust, and the whole is enclosed in brickwork, either in contact with the casing, or separated from it by a few inches, and is plastered on the outside, the plaster being covered with wood panelling. The cylinder cover is fitted with a false lid or cap, which encloses a thick layer of sawdust, and is thus protected from the cooling influence of the air. The space under the cylinder bottom is protected from the same influence by steam filling it from a branch of the pipe, H. C is the main beam, cast in two plates, which are bolted together with distance blocks between them to keep them truly parallel.

A catchpiece, A, is fixed to the upper part of the beam by means of brackets. On the piston reaching the bottom of its stroke, the catchpiece touches the blocks, B, fixed on the spring beams, arresting the piston, and thus preventing injury to the cylinder by the engine making too long an indoor stroke. E is a plug or tappet-rod for working the valves and cataract, and D the top nozzle shown in fig. 72.

The nozzle contains three valves, G. Fig. 72 is the governor, or regulating valve, for regulating the admission of steam into the chamber, E E, of the nozzle, whence it afterwards passes through the steam valve, F, into the cylinder. The governor valve is not moved by the engine during its working, but is regulated occasionally by hand. In proportion to the raising of the governor valve more or less, the steam is less or more wire drawn or reduced in pressure in its passage from the steam pipe into the cylinder. By this means, although the boiler pressure may vary, the mean effective pressure in the cylinder will be kept more constant.

The motion of the governor valve is under the control of the engine-man, and a handle is placed within his reach, which is connected by a rod and a lever with the valve spindle. F (fig. 72) is the steam valve, which admits steam into the cylinder. The chamber, E E, is not separated by the cover, B, as may be thought from the drawing ; but an uninterrupted passage is afforded for the steam, as shown by the arrows.

On the steam valve, F, being lifted (if the governor valve is also open), the steam is free to pass through it from the chamber, E E, to the passage, H, and thence by the steam port, J, into the

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of the cylinder. *K* is the equilibrium valve, and is in the middle of the nozzle. On being lifted, the steam piston is free to find its way along the equilibrium valve (figs. 71, 72, 73), and into the lower portion of the cylinder under the piston. At the moment the pressure of the steam above and below became equal, the rods, *R* (on account of their weight), hung at the other end of the beam, descend, and drawn upwards, the steam above acting as a cushion

The nozzle, *D*, has an external casing of thin iron, a space between it and the nozzle, which is filled up with

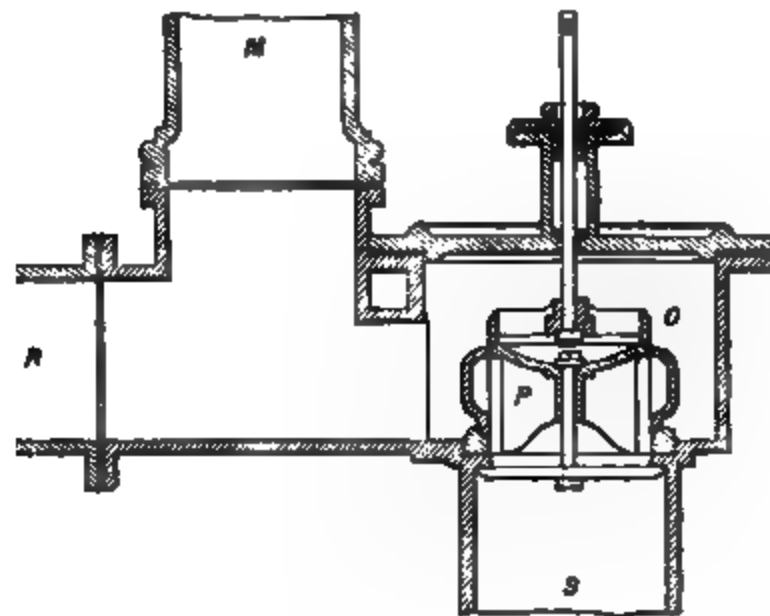


FIG. 73.—ENLARGED VIEW OF THE EQUILIBRIUM VALVE.

some other non-conducting material, to retain the

As seen in fig. 72 shows that the three covers, *C*, *A*, *B*, which cover the nozzle over the governor, steam, and equilibrium valves respectively, are of such a size as to allow of the valves being opened or repaired in removing the covers. *O* is the nozzle (figs. 71, 73), and shown in section in fig. 73; *P* is the exhaust valve, for opening or closing the communication between the lower part of the cylinder and the

Above the valve the nozzle chamber, *O*, is in communication with the cylinder by the lower part, and under the bottom of the nozzle communicates with the reduction

pipe, J on fig. 71, S on fig. 73. When the exhaust valve is raised, the steam in the lower part of the cylinder is exhausted into the condenser, L. That the action of the Cornish valve may be rendered plainer, an enlarged section of one is given in fig. 74.

The valve is designed to give a large extent of opening for the passage of steam with little traverse, a small amount of power being necessary to work it. E is the fixed seat, made of cast iron or brass, which forms part of, or is secured to, the valve chamber. C is a bell-shaped valve piece, also of brass, actuated by a rod, B. The valve

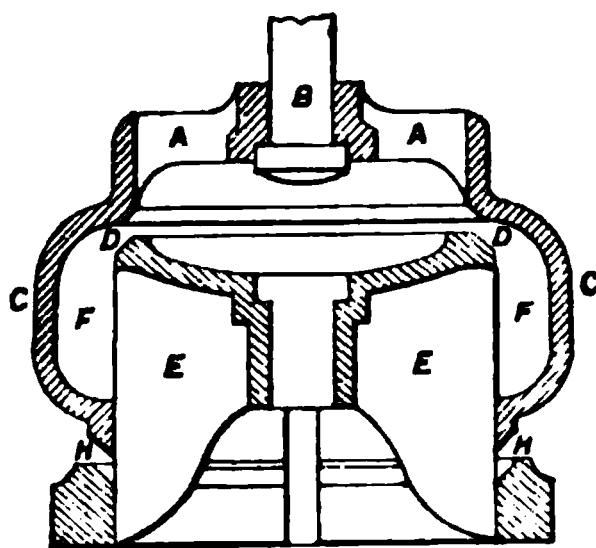


FIG. 74.—VERTICAL SECTION OF THE EQUILIBRIUM VALVE.

is in contact with its seat at two places, D and H, which are formed into accurate conical surfaces; the one, D, being internal, the other, H, external. When the valve is closed these surfaces accurately fit similar ones on the seat, and when lifted, as shown in fig. 74, two annular openings are formed at the same time, thus giving a double passage to the steam through the valve.

The spindle, B, of the valve, C, is fixed to a centre eye, cast in one with the valve piece, and connected to it by four arms, A A being two, the others being at right angles to them. The seat is also formed similarly, with four arms, having an annular ring at the base, the top edge of which is bevelled and ground to fit the lower edge of the valve, C, and, when lifted, forms the opening, as shown at H. Referring again to fig. 71, it will be observed that the piston rod is connected with the end of the beam by a parallel motion, which assures the ascent and descent of the piston rod in a vertical position, whilst the end of the beam moves through the arc of a circle.

A very striking feature of the Cornish engine is the cataract governor, G (fig. 74), shown also in section in figs. 75, 76.

This and the parallel motion were the inventions of Watt. It consists of a pump placed in a circular tank of water below the level of the cylinder. G is a barrel, and F the plunger, working in it as an ordinary small forcing pump. The water reaches the

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the inlet valve, H, which opens freely upwards; the outlet valve for the outlet is contracted as desired by a

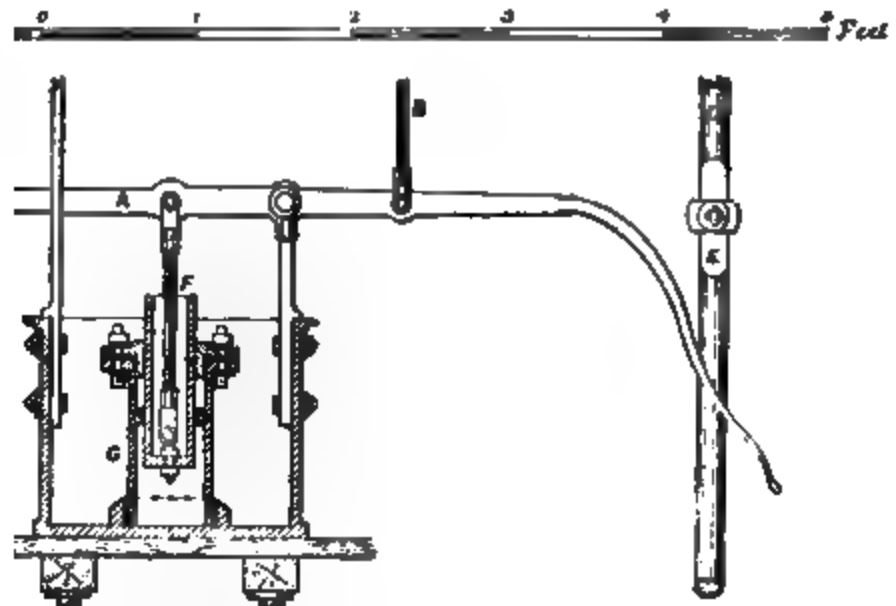


FIG. 75.—THE CATARACT GOVERNOR (SIDE VIEW.)

L. The plunger is connected by a joint to the lever, is loaded with a heavy weight, C, and on the same arm as the plunger, and the lever projects on the other side of the fulcrum, terminating in the handle shown on

the tappet or plug rod, D (which is worked off the main shaft) at the end of its stroke, a projecting

lower part of it, E, which strikes the end of the lever, and, in consequence,

the lever is raised, the water is raised through the valve, H,

the plunger in its downward stroke the completion of

the piston of the pump to ascend (due to the

imbalance of the equilibrium valve by

the tappet rod also raises the lever, A, and the weight, C, which is raised at the same time as the

weight, C, which is raised at the same time as the weight, C, which is raised at the same time as the

FIG. 76.—THE CATARACT GOVERNOR (END VIEW.)

the pump by forcing down the plunger. The inlet valve, H, having closed before the descent of the plunger, the only passage for the water is by the aperture left round the regulating plug, L. It will be seen, therefore, that the time occupied by the pump plunger in its descent depends upon the size of this aperture, which the attendant regulates by means of the plug fitting it.

Near the fulcrum of the lever, A, but on the tappet rod side of it, a rod, B, is jointed to the lever, and ascends vertically from it. In its ascent this rod opens first the exhaust, and shortly afterwards the steam valve, thus causing the engine to commence the next down stroke. The rod, B, acts upon a catch that releases weights, which, by their fall, open the valves, causing a suddenness of action, for which considerable advantage is claimed, especially as regards the admission of steam into the cylinder by the steam valve.

The interval of time between any two consecutive strokes must therefore depend upon the time occupied in the descent of the cataract plunger, and upon the amount of the opening given to the regulating play, L. By means of a micrometer screw and handle connected with L, by a rod, and the lever, M, the play can be regulated to any degree of opening required. The steam valve can thus be opened any desired number of times per minute, and the number of strokes in that interval of time thereby regulated.

J, fig. 71, is the eduction pipe, connecting the condenser, L, with the bottom of the exhaust valve nozzle, O. The size of the air-pump, N, is approximately half that of the steam cylinder, being 2 ft. 9 in. in diameter, with a 5-ft. stroke. It is fitted with a foot valve. P is an ordinary plunger-fed pump. The condenser, L, is fitted with an injection cock and valve for regulating the cold water supply to it. The pump rods, R, are frequently attached to the main engine beam, as shown on the drawing, without the intervention of a parallel motion, and with only side guides in the shaft. The consequence is that near the surface the rods deviate considerably from the vertical line in their ascent and descent; but this deviation is less at lower portions of the rods. It is a much better plan for the pump rods to be attached to the main beam by a parallel motion, so as to ensure the rods maintaining a

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position. This may be done by a gudgeon on the top of rods carrying two side-blocks working in cast-iron guides for sufficient length, to take the stroke of the engine. The gudgeon is attached to the beam by two iron radius rods, the space between them being filled with pitchpine. Husband's patent gear may be applied to the engine. In the event of breakage occurring is intended to open the equilibrium valve and stop the engine.

Steam in the Cornish pumping engine is admitted at high pressure, and may be worked expansively, the steam being cut off at the point of the stroke, which may be from one-third to one-half.

In consequence, however, of the great shocks to the cylinder, and especially the pit-work, when a high rate of expansion (with its accompanying high velocity during the stroke) is adopted, which shocks lead to breakage and stoppage of the engine, it is not found advantageous at work at any but a very moderate rate of expansion, and thus economy of steam is sacrificed for safety of working. The Cornish engine being single acting, it necessarily requires a larger cylinder for a given amount of work, than a double acting engine. As regards fuel consumed, when economically worked, from 3 lb. to 6 lb. of coal being used per indicated horse-power.

The Cornish pumping engine is a wonderfully elaborate and complicated specimen of ingenuity and skill, and its cost is about £100 per horse-power. A 90-in., or 500 horse-power, therefore costs about £4000; then the three-storied engine-house and foundations for such an engine, would require about 500 cubic yds. of masonry, the price of which varies in different localities, according to character and price of materials, such as stone, bricks, lime, &c. In Cornwall, where suitable stone abounds, it seldom exceeds £10 per yard. Again, the steam case must be covered with a non-conducting material, or else, having a greater surface than the steam cylinder, it becomes a larger condenser.

Another objection to the Cornish engine is the large number of parts to maintain in an efficient state of repair and cleanliness.

Four double-beat valves with their sets of bright nozzle gear, timing of pillars, levers, and guides, quadrants and catches on the round floor, tappet rod carrying its adjustable blocks to

work the four levers of double-beat valves and cataract governor in the basement; air-pump and condenser, with foot and delivery valves, injection cock, and valve and lever attachments; also a large cast-iron beam, which, for a 90-in. engine, weighs 50 tons, and the parallel motion with its many joints, all requiring a considerable amount of attention and care.

The *duty* of a Cornish pumping engine is the quality for which it is most renowned, and is the amount of work done in relation to the amount of fuel consumed.

The method adopted in Cornwall has been to find out what weight of water has been lifted one foot high by the consumption of one bushel = 94 lb. of coal. Of late years the bushel has been exchanged for the hundredweight of 112 lb. In America the standard is 100 lb. of coal.

This found out, the ascertaining of the weight of water lifted out of a mine of a given depth is simple. Thus, if an engine by the consumption of 112 lb. of coal lifts 60,000,000 lb. of water 1 ft. high, the amount raised out of a shaft of 100 fathoms = 600 ft. deep, would be 100,000 lb. This being the result of dividing the amount raised 1 ft. by the depth of the pit.

The engines at present working on the Cornish mines are all heavily loaded, pumping from great depths, in crooked, inclined shafts, entailing very considerable friction on the rods, and a late steam cut-off, which means less expansion in the cylinder, and a low duty. From the best information obtainable, it would appear that the average duty of these engines is not at present in excess of 60 millions.

The principle on which the Cornish pumping engine was designed, and which has just been described, met fully the conditions necessary for the economic drainage of the mines, and consequently no engine has heretofore held so high or meritorious a position.

These engines are a marvel of skill, and a lasting tribute to the brilliant engineers who designed them, as well as to the workmen who, in those early days of mechanical engineering, were able to manufacture such ponderous machinery.

This engine, however, has had its day, and while it may not yet have outlived its usefulness, yet there are few, if any, mines at

DRAINAGE OF MINES AND PUMPING MACHINERY.

- 1 the competent mining engineer would now advise the
on of a Cornish pumping engine.
- live in a progressive age, in which no machine, however

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FIG. 77.—HUSBAND'S SAFETY GOVERNOR FOR CORNISH PUMPING ENGINES.

lent in its design, or however perfect in its motion, can
in without improvement for well nigh fifty years.

usband's Safety Governor for Cornish Pumping Engines.—In
umping engines employed in mines the breaking of the
rods is an accident to be dreaded, and is likely to be

followed by serious damages to the machinery. The greatest strain is on the rods during their up stroke, when they have their own weight to support, and also that of the column of water in the bucket lift. This corresponds to the down stroke of the engine piston, which is then taking steam. On the rods breaking, the piston is suddenly relieved of its load, and the spring beams must suffer if the engine-man is not at his post. What the driver would do to prevent such a result, would be to throw up the equilibrium catch immediately he finds that the speed of the down stroke is faster than ordinary ; but to do this would necessitate his being constantly at the handles, and even then he could hardly throw up the catch in time. The object of the patent governor is to act simultaneously with the engine, and stop any tendency to race, before it ends in a disaster.

The action is as follows : The plunger, *z*, in fig. 77, makes its up stroke with that of the engine, and draws its water through the valve, *r*, forming part of the ordinary cataract system, described on page 104. The water so pumped is discharged into the same cistern, through the regulating cock, *d*, which is adjusted by means of a rod, *m*, from the engine floor. If the engine increases its speed above the normal rate of working, from any cause whatever, the water is throttled in its discharge through the cock, *d*, and a pressure is thus imposed upon the piston, *e*, tending to raise it ; as the piston, *e*, rises, the lever, *s*, comes in contact with the catch, *q*, and thereby lifts the equilibrium catch, *b*, thus introducing the steam to both sides of the piston. To increase its effectiveness, an additional cock, *n*, is provided, which closes as the piston, *e*, rises, thus increasing the force of the piston. The cost of one of these appliances is small in comparison with that which would be caused by the breakage of the rods.

The Geared Engine.—The pumping lift may be worked by many different kinds of engine, according to the quantity of water, the depth of the shaft, and the value of fuel.

For small quantities of water it is usual to put a crank on the end of the shaft of the winding drum, as shown in the illustration of a winding plant, figs. 41 to 44. The pump may then work intermittently at the same time as the winding, or the water may be allowed to accumulate in a large sump, from which it is

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FIG. 78.—DIRECT ACTION COMPOUND CORLISS PUMPING ENGINE.

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Where gearing is employed, the power from the engine is transmitted through a pinion on the engine shaft to a large spur-wheel, and on the shaft of this latter a crank is keyed from which the long connecting rod drives the surface bob, which in turn works the pumps.

The whole arrangement may be seen by reference to fig. 53, which shows a winding and pumping plant complete, together with the timber, pit head, and cages.

When a large permanent pumping plant is required, the engine, instead of being an ordinary single cylinder high pressure engine, as shown in the drawing, would be a compound condensing engine, such as a horizontal Corliss, by which great economy of fuel could be effected, and a high duty obtained. In this case the engine would have a separate house and be fed by two or more Lancashire boilers.

In many cases where there is a supply of water on the surface a large overshot waterwheel is erected, and the pumps connected direct to a crank on the wheelshaft; or a turbine or Pelton wheel may be used for the same purpose. This, of course, is the most economical arrangement of all.

The Direct Action Compound Pumping Engine.—Another class of pumping engines, often called Cornish pumping engines, is the crank and flywheel engine, which, in many localities, is employed for the drainage of mines.

In these engines the length of the stroke is constant, being, of course, determined by the crank, while the flywheel effects the same purpose as the ponderous rods in the Cornish engine—that is, it stores up energy at the beginning of the stroke which afterwards is given out and helps to complete it. These rotative pumping engines, such as that illustrated in fig. 78, have a high rate of duty, regarding which many extremely careful tests have been made.

The arrangement shown in fig. 78 is to be preferred to a geared engine when the total lift or length of pipes exceeds a single line of 10 in. diameter by 6 ft. stroke, raising water from 300 to 400 yds.

The engine is a twin compound horizontal Corliss, with a crank on the low-pressure side of sufficient strength to transmit the

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of the double engine, and also any excessive strains
ping and the method of connection. A double crank
engine crank receives the connecting rod for the pump
ie crank, and also the connecting rod of the low-
engine on the outside. This form of construction
the engines being placed as close as possible, thus
e width of the foundations to a minimum, and allowing
built up in a practically unbroken mass, and requiring
tely much less expensive foundations than vertical

ny form of horizontal engine is suitable to this arrange-
also offers the advantage of allowing one-half of the
e put up first, the other being erected when the pits
unk deeper, or the amount of water increased.

pound condensing engine, such as the one illustrated,
with a condenser of the jet style, and an air-pump not
e engraving, which may be of the direct connected
from the cross head or crank pin, or can be of the
t steam pump pattern.

nce or T-bob, shown in the illustration, is built of
n, working on a cast-iron turned axle. The balance
enclosed in a drum of sheet iron, and may be varied
o the amount required to balance the rods.

Acting Steam Pumps.—The next great improvement or
n steam pumping machinery was the invention of a
g steam pump in which there are no revolving parts,
ts, cranks, or flywheels; but in which the power exerted
a cylinder is transferred to the plunger or piston of the
direct line by means of a continuous rod. The first
his class was invented by the late Mr. Henry R.
n in 1840, and was used by him to feed the boiler
boat. Passing over the wearying details of the earlier
ns, we will briefly glance at the principal points in the
it of the direct acting steam pump by Mr. Worthington.
e year 1849, certain improvements were introduced by
hich the pumps could be operated by an ordinary slide
m this discovery may date the real introduction of this
np into general use. The next point to notice is the

radical departure from the large valves, having considerable lift, to a number of small valves, each one having but a small area and fraction of an inch of lift, but in the aggregate giving ample waterway ; by this means the valves are kept close to their seats ; they close quickly without shock, thus enabling greater speed to be attained than it is possible with a single valve, as, for example, that of the Cornish pump. This system of numerous small valves working, as it were, over a grater, forms a strainer which prevents the passage of foreign substances into the pump ; another advantage is, that if one or more of these valves receive a temporary or permanent injury, or even total destruction, it would simply impair the efficiency of the pump, and would not render it useless, as in the case of a single-valve pump.

Mr. Worthington applied the compound principle to his direct acting steam pump about 1854 ; this was easily accomplished owing to the simple construction of the pump. Another cylinder was added in direct line with the plungers and first cylinder. The power developed by both the cylinders was communicated to the plungers by the same piston rod, and in this simple manner the end was accomplished.

The steam, at boiler pressure, was admitted to the smaller cylinder, and exhausted thence behind the piston of the larger on the return stroke ; the rate of expansion of the steam being equal to the relation of the one cylinder to the other, and this usually is as 1 to 4.

One of the pumping engines erected at Cambridge, Mass., in 1856, had the following dimensions :—

High-pressure cylinder	.	.	.	.	.	12 in. diameter.
Low	„	„	.	.	.	25 in. „
Plungers	.	.	.	.	.	14 in. „
Length of stroke	.	.	.	.	.	25 in.

The capacity of this engine was equal to 300,000 gallons, raised 100 ft. high in 24 hours.

Another engine of similar size was soon after erected at the same place. It is interesting to note that on official trials these engines developed over 67 million duty. Compared with other engines then in use at American waterworks, they stood at the head of the list.

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The pumps being each double acting, a steady and continuous movement of the water in the column is the result. This movement is easy in its flow, and absolutely without the noise, jar, and recoil incident to the sudden starting into motion or bringing to rest of a heavy column of water.

The modern type of the Worthington duplex pump, as used for mine drainage, is shown in fig. 79.

The limit of expansion by means of compound cylinders had apparently been attained, with steam at ordinary pressures, in the above-described duplex direct acting steam pump.

Further efficiency from cutting off and expanding the steam in each cylinder by itself could only be gained by storing up energy in the early part of the stroke, and, to do this, neither crank, flywheel, nor massive reciprocating parts could be used, as any of these well-known devices would have deprived the duplex engine of its vital points of superiority and merit.

The desired result was, however, secured by a very simple, though highly-ingenious attachment, which the makers describe as follows :—

The high duty attachment consists, briefly, of two small oscillating cylinders attached to an extension of the plunger rod of the engine, preferably beyond the water end. These cylinders and their connecting pipes are filled with water or other liquid. Compressed air from a storage tank is admitted at a suitable pressure to maintain a constant load upon the pistons in the cylinders, through the medium of the interposed water. These pistons act in such a way with respect to the motion of the engine, as to resist its advance at the commencement of the stroke and assist it at the end, the air, meanwhile, exerting its unvarying pressure at each point of the stroke.

The two cylinders act in concert, and, being placed directly opposite each other, relieve the cross head to which they are attached of any sliding frictional resistance, and the engine of any lateral strain.

By thus alternately taking up and exerting power through the difference in the angle at which their force is applied with respect to the line of motion of the plunger rod, these two cylinders in effect perform the functions of a flywheel, but with the important

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mechanical difference that they utilise the constant pressure of compressed air instead of the energy of momentum. Their action is easily controlled, and their power can not only be exactly proportioned to the work to be overcome, but is entirely unaffected by the speed of the engine. The same amount of motion can be obtained in the same engine whether running at a piston speed of 10 ft. per minute or at 150. This latter feature is one of great importance, affecting, as it does so favourably, the economy of the engine when applied on any service where demand is irregular or intermittent. Where such service is performed by a flywheel engine it is a well-known fact that the economic results are attained only when the engine is running at nearly its full rated capacity, and that its economy falls as its speed is decreased. With every change in the rate of rotation of the flywheel a corresponding change in the position of cut-off must be made. When the speed is decreased the cut-off must be made to follow further in the stroke of the piston, reducing the expansion, and consequently the efficiency of the engine.

This high duty attachment enabled the duplex direct acting air pump to reach as high a duty as ever has been attained by a pumping engine, at a careful, thoroughly authenticated trial, indeed, these engines have replaced many of the high duty steam pumping engines both in Europe and America. The eminent firm of hydraulic engineers, Messrs. James Simpson and Co. of London, themselves the designers and builders of the best Simpson engines at the Lambeth Waterworks, London, recently replaced four of these engines by one Worthington air engine of their own manufacture. Messrs. Simpson state that these beam engines are historic, having been the most economical engines of their time. They were tested by Mr. W. A. Field, Mr. T. Hawksley, Mr. E. A. Cooper, and others; all the beam engines that have been made since are more or less designed on the same lines, and the substitution of a Worthington air engine to pump the supplies, in the place of its being done by beam engines, is the strongest testimony of their efficiency and ability.

The indicator cards shown in figs. 80 to 87 will illustrate the

precise automatic and uniform effect of the high duty feature of the Worthington engine.

In all pumping engines there are two completely antagonistic elements to be reconciled—viz., an elastic expanding vapour at one end, and an inelastic non-compressible fluid at the other. In moving the fluid an effect must be obtained as near absolute uniformity as possible, while to secure the greatest economy of steam expansion it is necessary to produce the widest practicable variation of pressure upon the steam pistons. It is obvious, then, that some means must be provided within the engine to equalise

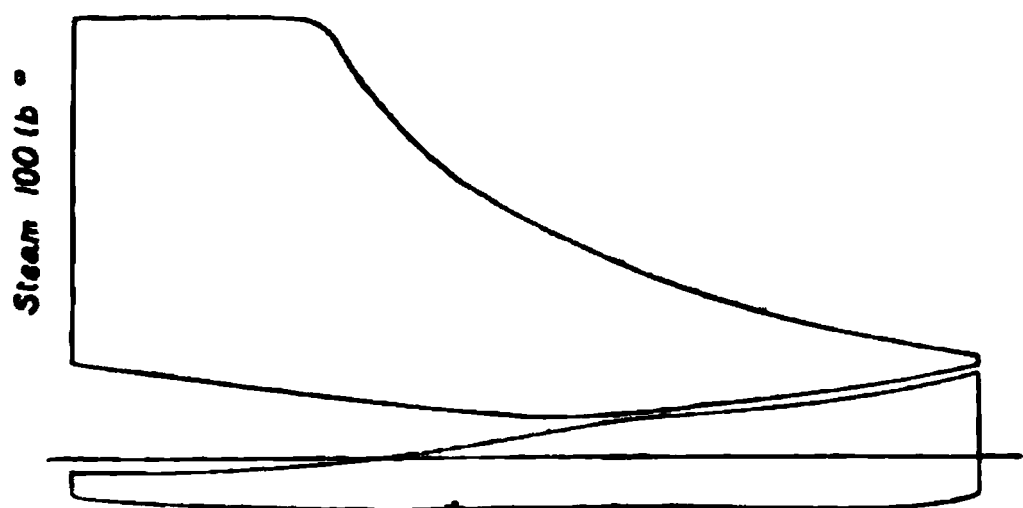


FIG. 80.—INDICATOR DIAGRAM.

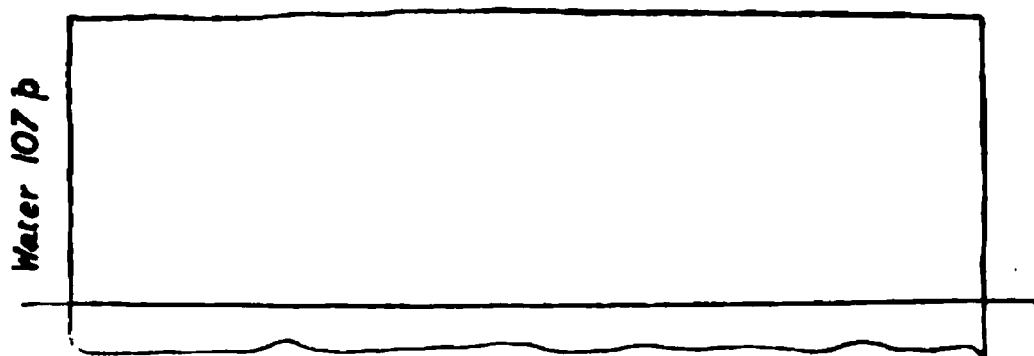


FIG. 81.—INDICATOR DIAGRAM.

these widely differing demands, and the completeness with which the compensating cylinders of the Worthington high duty engine meet these requirements is plainly shown by considering the steam cards from the engine in conjunction with the action of the compensating cylinders.

Fig. 80 is an indicator card, with diagrams from both high- and low-pressure cylinders; fig. 81 is a card from the water end or pump of the same engine, these cards being taken from a Worthington 5,000,000-gallon engine in service, running regularly against an average water pressure of 107 lb. It will be observed

throughout the stroke ; and to present a still closer comparison between the propulsive energy of the engine and the demands for uniformity made by the water diagram (fig. 83), we produce fig. 85 by overlaying the water diagram with the shaded part of the diagram in fig. 84.

It will be observed that the propulsive energy indicated in fig. 85 is slightly above the water diagram during nearly the whole stroke, just enough to cover the friction of the engine. At

FIG. 84.

FIG. 85.

the end of the diagram (to the right) is shown how the slight momentum of the moving parts of the engine assists in finishing the stroke, until they are arrested in their movement by the cushioning effect produced in the steam cylinders. The indicated energy of the steam power as controlled and distributed by the high duty attachment, showing an almost exact coincidence with the straight line forming the top of the water diagram, explains why the action of the Worthington high duty engine is absolutely smooth and noiseless.

3 PUMPING MACHINERY.

the compensator action. The indicating the resistance to the excess of the mean effective curve, below B, indicating the pressure when the terminal steam pressure. The lower portion of fig. 86 illustrates the various positions of the compensating cylinders throughout the stroke in forming the curve shown above. The action of this device is an admirable exponent of the principle of the parallelogram of forces; the hypotenuse, or the diagonal of the parallelogram, gradually increasing in length until, at mid-stroke, it coincides with the perpendicular, and the effect of the compensators falls to zero at a point where the mean effective steam pressure is just equal to driving the load, gradually increasing again until, at the end of the stroke, the resultant of the diagonal just makes up the deficiency imposed by expansion.

careful study upon the part of

ion of the high-pressure, low-pressure diagrams; the lower left shaded portion takes from the steam power the upper right shaded portion during the last half of the stroke to produce uniformity and coincidence

The following test of a Worthington engine, recently erected in America, is taken from the *Engineering News* of April 10th, 1892 :—

" Pumping Engine Tests at Lowell, Mass.—The test was made by Mr. George H. Barrus, M.E., on February 11th and 12th, and was conducted in accordance with the standard code adopted in 1890 by the American Society of Mechanical Engineers. A notable departure in this code is that the duty is stated in foot pounds per million heat units in dry steam delivered to the engine. This unit was adopted partially to avoid combining the duty of the engines with that of the boilers. It corresponds pretty closely to the generally used unit of 100 lb. of coal. If the coal used evaporates 10.36 lb. of water from and at 212° F. per lb. of coal, the heat units delivered to the engine will be exactly 1,000,000 per 100 lb. of coal burned.

FIG. 87.—COMBINATION OF THE HIGH PRESSURE, LOW PRESSURE, PUMP, AND COMPENSATOR DIAGRAMS.

"The Worthington high duty engine has been described and illustrated in our issues of August 17th and 31st, 1889, and its construction is now so familiar to most hydraulic engineers that we need not describe it again. The principal dimensions of the Lowell engine are as follow :—

Cylinder diameters : high pressure, 25 in. ; low pressure, 50 in. ; water, 27½ in.
Stroke, maximum length, 38 in.

Minimum cylinder clearance : high pressure, 2 per cent. ; low pressure, 1.5 per cent.

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pressure cylinder to low-pressure cylinder, 1 to 4'15.
pipe, 6 in. ; suction and force mains, 30 in.
ir above average water line in pump well during test,

nders are jacketed on sides and heads with
er, and in passing from the high-pressure to
inder the steam passes through a reheater.
reheater is taken from the drain pipe of a
ched to the engine, and it passes from the
jackets of the four cylinders. The condensed
nk, from which it is returned to the boilers
pump, working automatically. The main
boilers to the engine is 146 ft. long, and is
ia. Besides the separator attached to the
eparator is placed on the main steam pipe

The steam cylinders are lagged with mag-
ich is a layer of hair felting covered with

gine is supplied by two new horizontal return
brickwork with hollow side walls. Shaking
per cent. of air space are used. The flue
verhead brick flue, thence to the rear, and
brick drop flue into an underground flue
y. The overhead flue contains a feed-water
a plain wrought-iron shell without tubes,
nd 16 ft. long. The feed water is pumped
nd passes through this heater on its way to
op flue contains a damper controlled by a
per regulator.

6 ft. x 16 ft. in size with 140 3-in. tubes.
t. of heating surface and 36 sq. ft. of grate
8 to 1. The ratio of grate surface to com-
rough tubes is 6'5 to 1.

nsisted of a ten-hour run, the plant being
before, and kept in operation long enough
mity in the ten hours' working. The prin-
al were as follow :—

RESULTS OF TRIAL OF WORTHINGTON PUMP. 123

Average length of piston stroke (maximum 38 in.), 37·7 in.
 Temperature of water supplied to boilers by main feed pump, 170° F.
 Boiler pressure (by gauge on steam pipe), 96·2 lb.
 Total pressure against which pump worked, 85·06 lb.
 Percentage of moisture in steam, 0·38.
 Mean effective pressure, high-pressure cylinders, 43·14 lb.
 „ „ „ low- „ „ 15·53 lb.
 Duty per 1,000,000 h. u., 16,208,007 ft.-lb.
 Capacity per 24 hours by plunger displacement, 11,345,141 gallons.
 „ „ „ weir measurement, 10,876,008 gallons.
 Percentage of slip, 4·1.*
 Revolutions of engine per minute, 20·86.
 Indicated horse-power developed, all steam cylinders, 402·17.
 Work done by 100 lb. of coal (computed for whole time engine was in operation, after correcting for the heat lost by throwing away jacket water), 110,437,241 ft.-lb.
 Boiler test :—
 Draft in inches of water, 0·14.
 Temperature of escaping gases, 486° F.
 „ feed water entering flue heater, 106° F.
 Percentage of ash in coal, 8·1.
 Coal burned per hour per square foot of grate, 9·79 lb.
 Water evaporated per hour per square foot of heating surface, 2·1 lb.
 „ „ „ pound of dry coal, 9·55 lb.
 „ „ „ „ combustible from and at 212°, 11·64 lb.
 Coal consumed per indicated horse-power per hour, 1·69 lb.
 Total heat of combustion of coal obtained by calorimeter trial, 13,361 h. u.

“ Besides the new engine above described, the Lowell pumping station has a beam and flywheel compound condensing engine, built by Henry P. Morris, in 1873, and a compound duplex Worthington engine, built in 1875. On January 28th and 29th duty tests of these engines were made on the same plan as that followed in the test of the new Worthington engine. The duration of the test was 11 hours. The temperature of water supplied to the boilers from the hot well was about 60° less than in the

* It is believed that the weir measurement did not show the total quantity of water discharged to the reservoir, as it was designed for the measurement of a much smaller quantity of water, and there were reasons for doubting its accuracy. This is corroborated by the fact that an old Worthington engine tested just before, one of the plungers of which is known to have leaked badly, had a slip of only 3 per cent. ; and it is improbable that a new engine would have a larger slip.

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the new engine, which had some influence in lowering
 . The principal results shown by these engines were as

	Morris Engine.	Old Worthington.
1,000,000 h. u., ft.-lb.	77,418,178	54,777,009
24 hours by plunger, gallons	5,714,639	6,187,887
24 hours by weir, gallons	5,358,949	5,961,554
cent.	6.2	3.7
ns per minute	12.3	13.45
horse-power of all steam cylinders . .	172.12	190.12
er consumed per indicated horse-power		
ur (corrected for moisture in the		
lb.	21.7	30.2
100 lb. of coal, ft.-lb.	77,598,096	53,496,040

boiler test showed results not varying greatly from those
 above. It should be said that these two engines were in
 means perfect condition. The low-pressure piston of the
 engine showed excessive leakage, and it is stated that it
 packing ring. The bucket of the Morris pump leaked so

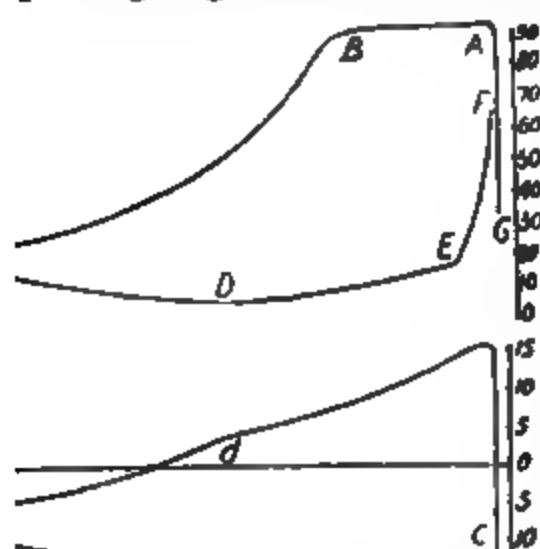


FIG. 88.—INDICATOR DIAGRAMS.

much that the wire drawing of the water could
 be plainly heard by one
 standing near the pump
 barrel. One of the
 Worthington pump
 plungers was tested for
 leakage with a water
 pressure of 50 lb. behind
 it, and a stream sufficient
 to nearly fill the 1½ in.
 drain valve leaked
 through. The Worthing-

h-pressure pistons also leaked badly.

ample indicator diagrams from the three engines are
 in figs. 88 to 90, and tell very plainly why it is that
 gh duty Worthington was able to do more than twice
 h work with a given amount of steam as the old Worth-

ington engine, and two-and-a-half times as much as the Morris engine.

“The indicator diagrams from the high duty engine are of somewhat peculiar shape, and it may be of interest to trace the action of the steam through one revolution. The high-pressure diagram is taken from the

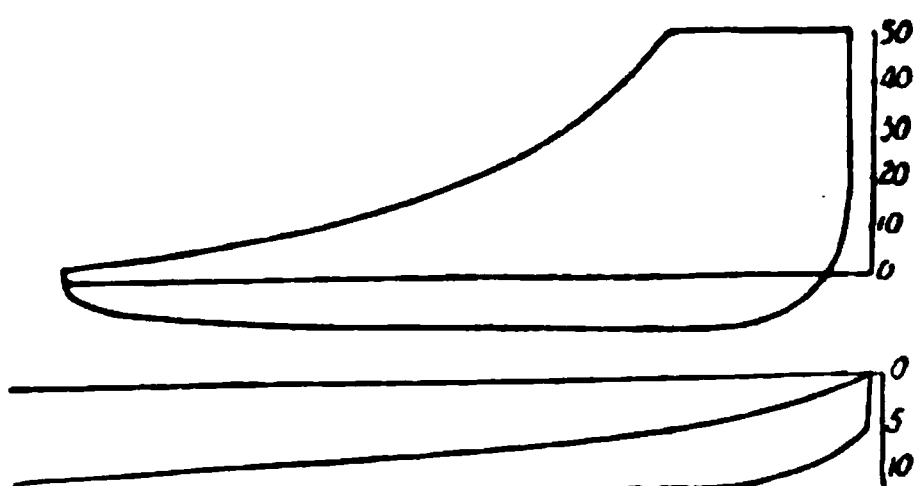


FIG. 89.—INDICATOR DIAGRAMS.

end farthest from the pump, and the low-pressure from the end nearest the pump. Beginning at the point (A) on the high-pressure card, steam at boiler pressure is admitted to the high-pressure cylinder, and at the same time the exhaust passage leading to the condenser from the low-pressure cylinder is opened (point *a* on the low-pressure card). At B the steam is cut off from the high-pressure cylinder, and expansion occurs through the remainder of the stroke. At *c c* both cylinders are placed in communication with the receiver; the pressure in the low-pressure cylinder instantly rises to 15 lb. and both pistons begin the return stroke. At *d* the low-pressure cylinder is cut off from the receiver, and expands the steam during the remainder of the stroke. The high-pressure cylinder still remains in communication with the receiver however, and as it forces the steam into it the pressure rises somewhat as the piston moves from D

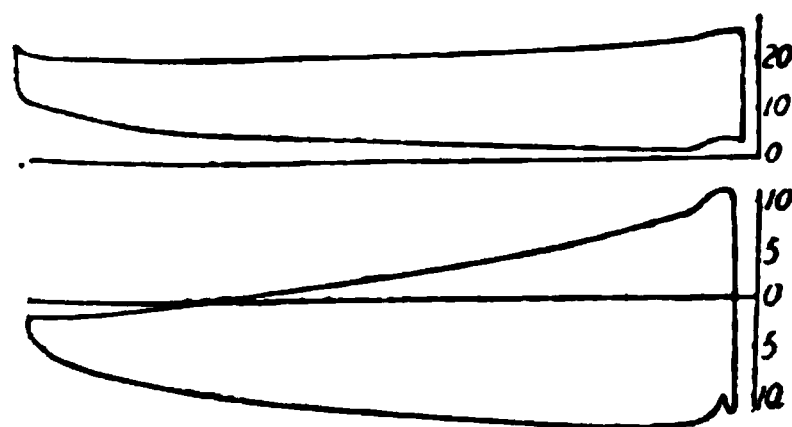


FIG. 90.—INDICATOR DIAGRAMS.

to E. At E the high-pressure piston covers the exhaust passage leading from the cylinder, and compression begins. At F the movement of the piston is retarded, while the valves in the water end seat themselves, and there is an escape of steam

through the dash relief valve, causing the sudden drop in the line to the point G. Live steam then enters, and another stroke begins.

Total pounds of feed water, including jackets, 12,408.

Pounds of feed per hour, 2068.

Total pounds of coal, gross, including ash, 1213.

Gallons pumped per revolution, 100.

Pump horse-power = $\frac{100 \times 10 \times 185.86 \times 20.25}{33,000} = 113.9$.

Indicated horse-power—mean of 48 diagrams, 123.34.

Pounds of feed per pump per horse-power per hour = $\frac{2068}{141}$ including jackets, 18.14.

Pounds of coal per pump horse-power per hour = $\frac{1213}{6 \times 114} = 1.77$.

Evaporation, pounds of water per 1 pound of coal, 10.2.

Efficiency, $\frac{\text{Pump horse-power}}{\text{Indicated horse-power}}$, 92.3 per cent.

Duty, assuming evaporation of 10 pounds of water per pound of coal, as required by contract = 122,000,000.

Duty on actual coal burnt, 125,100,000.

“It will be observed that the pounds of coal as actually used represent a duty of 125 millions, while 122 millions is the duty on an assumed evaporation of 10 to 1, so that the duty actually obtained is almost exactly the same as that calculated.”

The above results must be acknowledged as exceedingly good, and there is no reason why similar ones should not be obtained from an engine occupied in the drainage of a mine instead of in the supply of a waterworks.

The high duty attachment can be placed upon any Worthington engine. During the alteration the pump would not be required to stand idle except for a few days, and as a rule no alteration of the building, original piping, or foundations would be necessary.

The change which would result in the duty of the engine would be of at least 50 per cent., representing a saving of fuel of over 30 per cent.

Finally, the following table shows some comparative tests made between Beam engines and Worthingtons, and is full of instructive information. It may possibly be objected that this is waterworks practice, but it must be remembered that it is against the best known beam engines. Underground work would be similar, and as is shown on page 141, the loss of power in conveying steam a thousand feet or so is less than the immense friction of the rods of a Cornish engine:—

RE OF MINES AND PUMPING MACHINERY.

Engineer who conducted the trial.	Mr. E. A. Cowper, M.I.C.E.	Mr. Thomas Hack, M.I.C.E.	Prof. Unwin.	Mr. E. A. Cowper, M.I.C.E.	Mr. Osbert Chadwick.	Mr. W. H. White.
Head on Pump in feet	35	187.7 187.2	53.7 60.6	148.5	190.35	185.86
Efficiency per cent.	77.4	83.8 85.0	84.9 84.3	91.5	87.0	92.3
Feed water per actual horse-power (jackets being in circulation) : Pounds per hour	18.4	17.3 17.3	17.6 17.9	16.13	16.2	18.4
Pounds of water evaporated per pound of coal (ash and clinker included) on trial from the feed temperature	8.347 The jackets being in circulation.	9.44 9.37 The jackets being in circulation.	9.9 9.9 Including jackets.	7.74 Jackets in circulation.	8.01 Jackets in circulation.	10.2 Including jackets.
Duty in pounds of water raised 1 foot high per 112 lb. coal, including ash and clinker which are not deducted, and assuming the same evaporation as was found by Prof. Unwin, the full pump displacement being taken in all cases	112,626,200	118,094,000 117,650,000	111,500,000 111,500,000	121,032,000	123,300,000	128,200,000

The Worthington pumping engine is largely used at waterworks to pump direct into the mains ; it is also used for the more severe and trying service of forcing crude petroleum through pipes from the oil region to the Atlantic seaboard, in some places under a constant head of 900 lb. per square inch.

At one of the pumping stations of the National Transits Company's Oil Pipe Line, Osborne Hollow, there is a Worthington engine pumping 26,000 barrels per day against 900 lb. pressure. The high-pressure cylinders of this engine are 41 in. in diameter, the low-pressure 82 in. The engine develops about 750 horsepower ; the steam pressure used is 100 lb., $\frac{1}{4}$ cut-off, 16 expansions, and the average monthly efficiency of the engine is 100 millions. The high duty attachment of this engine weighs 3500 lb., and with the engine running under 16 expansions, with piston travel of 65 ft. per minute, it is estimated that the compensating cylinders are developing an energy that could not be imparted by a flywheel of less diameter than 40 ft., and weighing 400,000 lb. By this one example the difference between the Worthington high duty engine and the flywheel system is made very apparent.

Having thus briefly traced the rise and progress of the Cornish and rotative pumping engines, as well as the evolution of the high duty direct-acting steam pumping engine, or, as some call it, the American pumping engine, because it is entirely American both in its inception and complete development, we shall, in the next chapter, discuss the application of these engines to the drainage of mines.

CHAPTER VI.

MINING ENGINES (continued).

Conditions—The Cameron—The Worthington—
 The Deane—The Pulsometer—Station Pump—
 Underground—The Worthington Condenser—
 —Relative Efficiency of Station Pumps—
 Choice of Pump—High Duty Pumps in Mines—
 —Comparison with Direct Acting and Cornish
 Pumps—Relative Cost of Pumping Plants—
 Pumps for Mill Work—The California—The
 Duplex—The Centrifugal—Pump for Tailings
 —Memoranda relating to Pumps.

Two general classes of direct acting steam pumps are used in mine drainage—the sinking pumps, designed to work vertically, and the station pumps, which are designed to work horizontally. The sinking pump should be of as compact a form as can possibly be devised, having all the valves easily accessible, and valve and piston rods protected from flying stones, resulting from shots. We might summarise the requirements of a good sinker: (1) compactness, so as to occupy the minimum space in the shaft for the maximum quantity pumped; (2) strength to resist hard blows and rough usage, incident to a machine that must be kept steadily at work, at points within 20 ft. of the shaft bottom; (3) economy. This is placed last, because it is of least importance. The sinking pump is naturally of a temporary character, and is replaced by a station pump when the shaft is

completed, therefore the pump that can stand hard knocks, and occupy the smallest space for a given pumping capacity, must be the most efficient as well as the most economical in the long run. In shaft sinking a few minutes' stoppage of the pumps may often cause an hour's delay, to drain the water, so that the men can resume sinking.

The first principle involved in the application of direct acting steam pumps in mines, is to have a continuous acting machine — one that will never stop for repairs or renewals and consequently cannot be drowned out, with the ordinary flow of water that it is designed to handle. As no machine, however perfect, can fill these conditions, the only solution is to have two pumps, one working, and the other in perfect order, and ready to start up

FIG. 93.—THE WORTHINGTON SINKING PUMP.

immediately steam is turned on. This we shall designate as the duplicate pumping system, and again state that it is the only safe and reliable method to pursue, whether it be in the sinking

PUMPING ENGINES.

ut an old mine, or sinking for a new one, or lastly
ump for the permanent drainage. In each case
be in duplicate, so as to ensure constant work.

The Cameron sinking pump (fig. 92), is the
one in more general use in the mines of the
Western States, while the Deane (fig. 94),
and the Knowles, are not used as extensively
as they might be, but are being gradually in-
troduced.

THE WORTHINGTON SINKING PUMP.—The
sinking pump, shown in fig. 93, is designed to
work vertically in sinking mine shafts, recovering
flooded mines, and for mine pumping work
requiring the use of an efficient steam pump,
which shall be positive in its operation, quiet
in action, compact in its design—thereby
occupying the least possible amount of space—
and built in the strongest manner, so as to
withstand the hard usage to which pumps on
this service are, as a rule, subjected.

The water plungers are double acting, working
through exterior stuffing boxes and adjustable
packing. Means are provided, as will be seen,
for either suspending the machine at the link
shown on the ends of the steam cylinders, or
for hanging it on suitable timbers on the sides
of the shaft.

The suction opening is at the lower end of
the pump, which is the most convenient place
for attaching the suction pipe or hose. The
discharge connection to column pipe is on the
side. The water valves are inclosed in heavy
pots, and are made accessible for examination
ans of swing bolt-covers on the valve pots.

this pump is duplex, and fitted with the Worth-
tion makes its operation positive. It is always
nd when running there is an entire absence of the
n which results from the use of single pumps, and

which often causes serious trouble and annoyance by bursting the column pipe. Being self-contained and working with perfect smoothness, the strain on supports and hanging irons is, of course, reduced to a minimum.

THE DEANE SINKING PUMP.—This pump, which has already been referred to, is illustrated in fig. 94. It may be slung on chains, as shown, or temporarily hung on to a bearer. The steam is supplied from the surface under a pressure of 50 lb.; and a pump having a steam cylinder 18 in. diam., with a bucket of 18½ in., plunger of 13 in., and a stroke of 24 in., will raise 500 gallons per minute, to a height of 150 ft. The same pump with certain modifications, will raise 7000 gallons per hour to a height of 200 feet.

The valves are so constructed as to be easily accessible, and the water passages large and direct, so as to offer but little resistance to the flow of water. The objection to steam pumps for sinking operations is the exhaust steam; but, if desired, a special condensing arrangement can be attached, which will do away with this difficulty.

For very gritty water a special pump can be obtained, with valves adapted to the circumstances. The pumps are all strongly made, and but little liable to get out of order.

THE PULSOMETER.—Another form of pump, which is preferred by many for shaft sinking and kindred purposes, is that known as the "Pulsometer," an invention which is in fact a perfection of the principle of Thomas Savery, in 1698.

The pump is shown in fig. 95, and in section in fig. 96, and, as now constructed, consists of a hollow chamber, called the body, composed of two pear-shaped castings forming water chambers, with their necks joined above, between which is the air vessel, while the discharge chamber is at the lower end of the body; to which, in fig. 95, will be seen attached the rising main of wrought-iron pipes. The steam arrives by the flexible hose, and, the steam valve being opened at K, fig. 96, the steam passes into that chamber, A, which is not closed by the ball, 1, at the apex of the pump, and gently depresses the water without agitation, forcing it through the discharge valve into the delivery pipe. The moment that the water uncovers the passage leading into the discharge

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chamber, the steam passes underneath the water, and is suddenly condensed, forming a vacuum which draws the ball valve over, thus shutting off the steam from one chamber and allowing it to pass into the other. The vacuum at the same time opens the suction valve, E, and draws the chamber full of water from the suction pipe; meanwhile, the steam is emptying the other side of the pump; and so the action goes on surely and regularly, without in-

FIG. 96.—SECTION OF THE PULSOMETER PUMP
termission, so long as steam is supplied, and there is water to be pumped. The change from one vessel to another is so rapid that, even without an air vessel on the delivery, but little pause is visible in the flow of the water, and the stream, under favourable circumstances, is nearly continuous.

There are only five moving

parts,—the steam admission valve, the two suction, and the two delivery valves ; and as there are no complicated internal parts, the pump is very suitable for working with water mixed up with grit, as in sinking, or draining levels which have been flooded. The pump can be slung by a rope or chain in the shaft, being raised or lowered as required, while in the case of a recent sinking in a Scotch pit, three sets of three pulsometers were used, one set lifting to the other, and the whole suspended by chains, the entire arrangement working very satisfactorily. As the steam is condensed within the pump for suction purposes, there is consequently no exhaust, a fact which of itself is an advantage in confined situations.

The pulsometer will raise water to heights of from 70 ft. to 80 ft., and draw from about 10 ft. to 12 ft. The steam pressure for lifts of from 20 ft. to 40 ft., should not be less than 20 lb. to 30 lb. per square inch, and from lifts of from 40 ft. to 80 ft., not less than from 30 lb. to 50 lb.

In the simple pulsometer it is impossible to obtain an expansive action of the steam, because the upper valve, whether a ball or other contrivance, must, from its construction, be allowing the steam to pass into one or other chamber during the whole time the pump is at work. Where the work is constant, and there is a good margin between the pressure of the steam and the pressure of the water in the column, a patent automatic cut-off attachment called the Grel may be employed with advantage, especially to pumps larger than the size known as No. 4. An economy of from 40 to 50 per cent. of the total steam consumption is said to be effected by this arrangement, which depends upon the employment of a secondary cut-off valve, in addition to the distributing valve, which admits of a long interval between each pulsation, during which no steam can pass through the steam pipe, although the work of pumping continues.

The pulsometer is made in sizes, capable of raising from 900 gallons to 80,000 gallons per hour, at prices varying from £8 to £170.

Station Pumps.—There are many excellent pumps made by various manufacturers in America specially designed for underground station work, all having and combining several good

hington and Knowles duplex pumps are the more extensively used, especially by those persons who can distinguish between a good pump and a cheap pump.

The style of station pump in most general use is the duplex compound condensing; the condensing apparatus being a separate and distinct pump.

The Worthington patents being still in force, the duplex condenser made by this company is the only one obtainable, the other pump-makers being obliged to content themselves with a single pump condenser, with their uncertainty of action and associated evils.

The Worthington Condenser consists of a duplex pump and an injector condenser, as illustrated in fig. 97, and is so arranged that the water and exhaust steam

FIG. 97.—KNOWLES PATENT COMPOUND CONDENSING DUPLEX MINING PUMP WITH INDEPENDENT AIR PUMP AND CONDENSER.

is employed to assist the pump in maintaining the vacuum in the condenser. As a direct effect of this combination, the vacuum in the pump cylinders is less in degree than that obtained in the injector condenser and exhaust pipe.

Consequently the load upon the pump is lightened, and the cost of producing the vacuum is materially reduced. In all other types of condensers and air-pumps the vacuum in the pump cylinders is necessarily greater than that in the condensing chamber.

The valve motion is a prominent feature of the condenser. To it is due the complete exemption from noise or concussive action. The two pumps are placed side by side, and so combined as to act reciprocally upon the steam valves of each other. One piston acts to give steam to the other, after which it finishes its own stroke and waits for its valve to be acted upon before it can renew its motion. This pause allows all the water valves to seat quietly, and removes everything like harshness of motion.

As one or the other steam valves must always be open, there can be no dead point. The pump is therefore always ready to start when steam is admitted, and is managed by simply opening and shutting the throttle valve.

A longitudinal section of the Worthington condenser is shown in fig. 99. *A* is the vapour opening, to which is connected the pipe that conducts to the apparatus the steam or vapour that is to be condensed, and in which a vacuum is to be made and maintained. The injection water used to produce the condensation of the steam or vapour is conveyed by a proper pipe attached to the injection opening at *B*.

Over the end of the spray pipe, *C*, is placed a cone, provided with wings that thoroughly separate and distribute the water and insure its complete admixture with the steam. This cone is adjustable by means of a stem passing through a stuffing box at the top of the condenser. Any floating material that can pass an ordinary strainer will not lodge around this cone; but should it become obstructed from any cause, it can be washed clear by simply lowering it by means of its stem.

These condensers are very efficient, and, being self-acting and entirely separate from the main pumping engine, they can be

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England, however, the high duty attachment is sometimes used on pumps developing as low as 30 horse-power.

Lastly, the high duty Worthington pumps are also used in mines. These pumps have already been described, and are

FIG. 99.—SECTION OF THE WORTHINGTON CONDENSER.

undoubtedly the most useful and efficient, as well as the safest, pumping engine ever introduced for mine or for waterworks service.

Coming to the relative efficiency or duty of these three classes

PUMPING ENGINES.

18. I recently submitted to one of our principal a proposition involving the delivery of 500 gals. minute, against a head of 3000 ft., and in reply that a compound condensing pump would consume 1060 lb. of coal per hour ; a triple expansion pump 1060 lb. a high duty Worthington pump would consume 1060 lb. per hour.

It was based upon the use of high-class boilers which furnish steam slightly superheated, and with the best It will, however, serve for a basis of comparison. If the compound condensing pump as unity, we find that triple expansion gives a saving of 22.63 per cent. of the high duty Worthington a saving of 38.68 per cent. in the compound condensing pump. Or, taking in order, the coal used in the high duty engine is as triple expansion, and as 1 to 1.63 in the compound engine.

On the sort of pump to adopt for any particular case the engineer has to take into consideration, first, the possible ; second, the cost of fuel ; and, third, the difference between compound condensing, triple expansion, and high duty pumps. If the pump is to be used on the mine, or, better still, erected in place in the shaft, the cost of the better class of pump must be charged with an interest of 10 per cent. per annum. Taking these into his calculations, the engineer will arrive at the conclusion that for the majority of Western mines the compound condensing pumps are all that is required ; while for shaft sinking and inspecting work, even compound condensing pumps are speedily replaced by the very extravagant high-

pressure pumps of a permanent character, however, and in places where the best classes of triple expansion and high duty pumps are in order.

Pumps in Mines.—We have seen that in waterworks a high duty pump can easily do 110,000,000 duty service conditions. The same duty can be obtained if the pump is placed in the station of a mine, less, however, in conveying the steam from the boilers at the

surface to the pump below, and this loss with the best non-conducting pipe covering is very small, and is in fact much less than the loss in friction conveying power by means of rods, as in the Cornish system. In this connection we may quote the experiments made in actual practice. At the Wolftone Mine, Leadville, Colorado, steam was conveyed 600 ft. through a 5-in. pipe, covered with 1 in. of hair-felt composition to the pump station in the mine.

It was found by carefully conducted experiments that the condensation amounted to 100 lb. per hour. The full capacity of the pipe with steam at 80 lb. pressure, and velocity of 50 ft. per second, is 4804 lb. per hour; therefore the loss by condensation is a little over 2 per cent. of the steam used in the pump. It follows that with the pipe used only at half its capacity the loss would be about 4 per cent., or in other words 4 per cent. more fuel. The loss in pressure was very slight. Taking these figures as a basis, we find that a high duty engine of a similar capacity to the Wolftone pump would at surface develop, say 100,000,000 ft.-lb.; at 600 ft., 2 per cent. less, or 98,000,000 ft.-lb.; at 3000 ft., 10 per cent. less, or 90,000,000 ft.-lb. The advantages claimed and usually admitted on behalf of the Cornish engine are (*a*) economy of fuel; (*b*) safety from flooding; (*c*) reliability in action. To get these points, enormous first costs are entailed to purchase and erect the ponderous machinery, while the cost of repairs and ordinary wear and tear are also heavy.

In comparing these points of advantage with the direct acting steam pumps—

(*a*) We have seen the high duty Worthington pump is more economical than the Cornish engine and is replacing it rapidly in England.

(*b*) While it would appear that the Cornish engine itself, situated at the mouth of the pit, is absolutely secure against flood, yet on the principle that the strength of a chain is but that of the weakest link, and that the plungers at the various levels are very essential parts of the engine, we see that a stop to repair any of the plungers or other parts of the engine must result in a temporary flooding of the mine, interfering with the progress of shaft-sinking or work on the bottom level, while a serious

A lift of pumps in a mine may cause great fatigue the lowering of a new lift of pumps to It is seldom that we find a Cornish pumping work, with more than one-third of its total capacity in reserve. Let us assume that an engine has to raise 300 gallons per minute in order to drain a mine, and in case of need can lift 450 gallons steadily without unnecessary risks. We have seen, however, that the direct action steam pump must be in duplicate, each pump having, say, one-third of its capacity in reserve; therefore, while the ordinary working capacity of each pump would be, say, 300 gallons per minute, to be increased to 450 in case of a sudden increase of water, or if an inundation should occur both pumps could be started, yielding a combined flow of 900 gallons, now it is evident that a steam pumping plant so arranged is less liable to flooding than is a Cornish plant, and by it work can be carried on uninterruptedly at the bottom level of the mine.

FIG. 100.—PLAN OF THE CALIFORNIA PUMP.

(c) The Cornish engine, with its ponderous rods, balance beams, angle beams, etc., is more liable to become deranged or to break in some of its numerous parts, than is the direct acting pump, while the irregularity in the motion of a Cornish engine causes sudden and heavy pressures, hammer-blows, as a rigid mass of reciprocating rods equally rigid column of water at varying from a state of rest up to a velocity of several feet per minute, and again coming to a state

of rest all of which cause sudden strains which sooner or later end in breakage.

On the contrary, in the direct acting pump any irregularity in the water column is taken direct on the steam piston, the steam forming an elastic cushion, as it were, to receive all the shocks; while even if the water column of a high duty engine burst right at the pump, for example, the engine could not complete its stroke. On the other hand, should the rods of a Cornish pump part, a new engine is usually required in order to make good the repairs.

The relative cost of the pumping plants varies

SUCTION

FIG. 101.—ELEVATION OF THE CALIFORNIA PUMP.

and placed at work in a mine for from one-third to half the cost of a Cornish beam engine in working order.

PUMPS FOR MILL WORK.—It is not always possible to obtain a supply of clean water from a height which will feed it direct into a cistern at the top of the mill, and in these cases some kind of pump must be used to raise the water required for concentration purposes up to the height required to feed all the machines.

For this purpose there are a large variety of pumps in the market, such as those connected with the names of Tangye, Worthington, Hayward, Tyler, and many others, and of these a full description will be found in a work by Mr. Stephen Michell on "Mine Drainage."* It will be sufficient for our purpose, however, if I describe the pumps used in a mill erected by my-

* "Mine Drainage," by S. Michell. Messrs. Crosby Lockwood and Son.

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by the use of the two double acting pumps, the water being delivered in a constant stream.

The pumps are of the internal plunger type, and the plungers are packed by removing the end cylinder covers. If asbestos packing is used it will be found to last for a long period without changing, though, if a knocking sound is heard inside the pump, it is a sign that the packing either requires renewal or the gland wants screwing up.

In places where fuel is scarce and expensive, the duplex pump is provided with an extra pair of cylinders, the pistons of which are operated by the exhaust from the cylinders to which the steam is first admitted. In other words, the pump is compounded and advantage taken of the expansion of the steam, and the economic effect of a cut-off is realised.

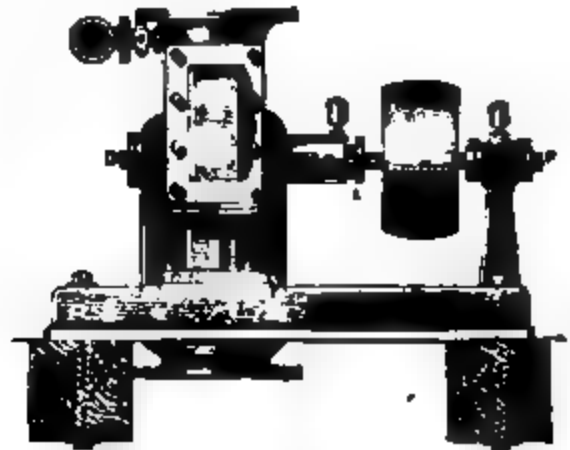
DUPLEX STEAM PUMPS, WITH INTERNAL PLUNGERS.—DIMENSIONS AND CAPACITIES OF A FEW SIZES.

Diameter of Steam Cylinder, in inches.	Diameter of Plungers, in inches.	Length of Stroke, in inches.	Capacity at 50 feet Piston Speed per minute, in gallons per hour.	Capacity at 85 feet Piston Speed per minute, in gallons per hour.	Size of Steam Pipe, in inches.	Size of Exhaust Pipe, in inches.	Size of Suction Pipe, in inches.	Size of Discharge Pipe, in inches.
6	4	10	3,200	5,440	1½	1½	3	3
7½	4½	10	4,050	6,880	1½	2	3½	3½
7½	5½	10	5,500	9,350	1½	2	4	4
9	5½	10	5,500	9,350	2	2½	4	4
10	6	10	7,300	12,200	2	2½	4½	4½
11	6	10	7,300	12,200	2	2½	4½	4½
11	10	10	20,000	34,000	2	2½	7	7
11	10	15	20,000	34,000	2	2½	7	7
12	7	10	9,800	16,600	2½	3	5	5
12	8	10	12,800	21,700	2½	3	6	6
13	9	10	16,200	27,500	3	3½	7	7
14	7	10	9,800	16,600	3	3½	5	5
14	8	10	12,800	21,700	3	3½	6	6
14	10	10	20,000	34,000	3	3½	7	7
16	9	10	16,200	27,500	3	3½	7	7
16	10	10	20,000	34,000	3	3½	7	7
16	12	10	28,800	48,900	3	3½	8	8
16	14	18	39,200	66,400	3	3½	10	10
18	10	10	20,000	34,000	3½	4	7	7
18	12	10	28,800	48,900	3½	4	8	8
20	15	15	45,000	76,000	3½	4	12	12

NG ENGINES.

ie concentration of metalliferous ores
nuous supply of fresh, clean water is
, however, that the mill is so situated
ar. In these cases the same water
er again after first passing through
heavier slimes are deposited. The
means clean, and those who have
ter charged with fine mineral matter,
i, can best appreciate the difficulties

has practically no valves is especially
and the centrifugal pump has been
/ waters have to be dealt with, as in



THE CENTRIFUGAL PUMP.

251 to 264. This form of pump is
e the total lift is greater than from
se should it be placed at a greater
surface of the water to be raised.

pump is shown in figs. 103 and 104,
easily be erected upon a couple of
ry, or on a masonry foundation for

that the joints of the suction pipes
ght, and that the gland, E, round the
D, does not leak.

oints is best tested by allowing the
with the pipes full of water, when, if
bably show itself.

When the water to be raised is below the centre of the pump spindle, the pump must be charged before it can deliver any water.

This is done by filling the suction pipe and pump case full of water while the pump is at rest, to at least as many inches above the top of the fan, as there are feet of suction below it. For this purpose a tap and funnel are fixed into the pump casing, while the valve in the straining box, at the foot of the suction pipe, prevents the escape of the water at the lower end.

The charging may also be effected by means of a steam ejector placed above the fan, but the former process is the more usual. As soon as the suction pipe is filled, the spindle is set in motion in the direction of the arrows cast on the case, and the water will begin to rise.

The sizes and power required for these pumps, as well as their approximate prices, are given in the following table. The speed varies, with the height of the lift, from 500 to 1000 revolutions per minute, and the duty is about 65 per cent. of the power expended.

Size of Pumps and Diameter of Pipes in inches.	Gallons raised per Minute.—Maximum Quantity.	Diameter of Riggers by Width of Face in inches.	Width of Belt in inches for 20-ft. Lift.	Kind of Belt.	Nominal Horse-power of Engine for 1 ft. high.—Maximum Quantity.	Pump complete, as figs. 1, 2, 3, 4, 5, & 6.	Pipes per foot, in 3 ft., 6 ft., or 9 ft. lengths, with Bolts and Joint Rings.
						£ s. d.	£ s. d.
3	150	8 x 4	2	Single Belts.	0·045	12 0 0	0 2 3
4	260	9 x 4	2		0·078	13 0 0	0 2 10
5	400	9 x 5	2½		0·121	16 0 0	0 5 5
6	580	10 x 6	3		0·175	17 0 0	0 6 0
7	800	11 x 6	3½		0·242	17 10 0	0 7 0
8	1,000	11 x 7½	4		0·303	18 10 0	0 7 3
10	1,600	11 x 7	4	Double Belts.	0·484	24 0 0	0 8 6
12	2,300	13 x 9½	5		0·7	35 0 0	0 11 0
13	2,700	14 x 10½	6		0·818	40 0 0	0 12 3
16	4,100	21 x 10½	7		1·242	67 0 0	0 15 0
18	5,300	24 x 10	9		1·606	80 0 0	0 17 0
20	6,500	30 x 11	10		1·97	95 0 0	0 19 0
24	9,400	36 x 15	14		2·848	140 0 0	1 4 0

PUMPS FOR PUMPING THE TAILINGS FROM BATTERIES.—Very great difficulty has been experienced in pumping tailings, owing

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11·2 gallons	= 1 cwt.
224 „	= 1 ton.
1 cubic inch	= 252·45 grains, or ·03617 lb.
12 „ inches	= ·434 lb.
1 „ foot	= 6·25 gallons, or 1,000 oz., or 62·5 lb.
1·8 „ „	= 1 cwt.
35·84 cubic feet	= 1 ton.
1 cylindrical inch	= ·02842 lb.
12 „ inches	= ·341 lb.
1 „ foot	= 5 gallons, or 49·1 lb.
2·282 „ feet	= 1 cwt.
45·64 „ „	= 1 ton.
1 cubic inch of mercury	= 3425·25 grains.
1 „ foot of sea water	= 64·14 lb.
Weight of sea water	= weight of fresh water × 1·028.
Cubic foot of fresh water	× ·557 = cwt. approximate.
„ „ „	× ·028 = tons.

Useful Numbers for Pumps.

D	= Diameter of pump in inches.
S	= Stroke „ „
$D^2 \times S \times \cdot7854$	= cubic inches.
$D^2 \times S \times \cdot002833$	= gallons.
$D^2 \times S \times \cdot00045$	= cubic feet.
$D^2 \times S \times \cdot02833$	= lb. fresh water.

Pressure of Water per Square Inch at Different Heads.

P = Pressure in lb. per square inch.

H = Head of water in feet.

$P = H \times \cdot4333$. Roughly every foot of elevation = $\frac{1}{4}$ lb. pressure per square inch.

$H = P \times 2\cdot31$.

Pressure per square foot = $H \times 62\cdot4$.

To find the quantity of water which an engine will pump from a given depth.

Multiply the horse-power by 550 and divide the product by the depth of the pit in fathoms ; or—

$$\left. \begin{array}{l} \text{Let } H = \text{Horse-power of engine.} \\ \text{„ } F = \text{Depth of pit in fathoms.} \\ \text{„ } G = \text{Quantity of water in} \\ \quad \text{gallons per minute.} \end{array} \right\} \begin{array}{l} \text{Then } G = \frac{H \times 550}{F} \\ \text{„ } F = \frac{H \times 550}{G} \\ \text{„ } H = \frac{F \times G}{550} \end{array}$$

PUMPING ENGINES.

e for calculating the quantity of water drawn at a single in a working barrel of a given diameter :—

are the diameter in inches, and divide by 10 for the gallons ft. stroke. (See also page 94.)

e for ascertaining the weight of water in pipes, reckoning to the gallon :—

are the diameter in inches and the result will be pounds of water in a 3-ft. length.

PUMPING ENGINES.—The data required for ascertaining the power required to do a given amount of work in pumping, multiply the quantity to be raised in a given unit of time, and height to which it is to be raised. The quantity is to be added to the weight in pounds raised per minute, and this is to be multiplied by the height in feet, and the product divided by 33,000, in order to find the horse-power required to do the work in question. The standard which has been adopted to represent the work of one horse, is equal to 33,000 feet raised through a space of 1 ft. high in a minute.

A gallon of distilled water at a temperature of 60° Fahr., weighs 10 lb. avoirdupois; so that by adding a cipher to any quantity expressed in gallons, its weight in lb. is obtained. For instance that it is required to find the horse-power of raising 350 gallons of water per minute to a height of 170 ft. Then $350 \times 10 = 3500$ lb. to be lifted per minute, and $3500 \times 170 = 595,000$ lifted one foot high per minute, and $\frac{595,000}{33,000} = 18$ horse-power.

When the quantity of water is expressed in gallons to be raised in 24 hours to a given height, it is necessary to divide this quantity by 1440, in order to find the quantity per minute; or, if the quantity in gallons to be raised to a given height per 24 hours is divided by 10 to bring it down to lbs., and then by 33,000, the horse-power required to lift it is obtained direct. This may be represented by the formula as follows :—

G = Number of gallons to be raised in 24 hours.

H = Height in feet to which it is to be raised.

HP = Horse-power required.

Then—

$$HP = \frac{G \times h}{4,752,000}$$

To which, however, it is usual to add from 70 to 80 per cent. in order to allow for loss in friction and contingencies.

The area of the steam piston, multiplied by the steam pressure, gives the total amount of pressure that can be exerted. The area of the water piston, multiplied by the pressure of water per square inch, gives the resistance. A margin must be made between the power and the resistance to move the pistons at the required speed, say from 20 to 40 per cent. according to speed and other conditions.

To find the capacity of a cylinder in gallons. Multiplying the area in inches by the length of stroke in inches will give the total number of cubic inches ; divide this amount by 231 (which is the cubical contents of a United States gallon in inches) and product is the capacity in gallons. When divided by 277.27, the answer will be in Imperial or English gallons.

WEIGHT AND CAPACITY OF DIFFERENT STANDARD GALLONS OF WATER.

	Cubic Inches in a Gallon.	Weight of a Gallon in lb.	Gallons in a Cubic Foot.	Weight of cubic foot of water English standard, 62.321 lb. Avoirdupois.
Imperial or English . . United States	277.274 231.00	10.00 8.33111	6.232102 7.480519	

A “miner’s inch” of water is approximately equal to a supply of 12 United States gallons per minute, and varies from 1.36 to 1.73 cubic ft. per minute. See also pages 22 to 27.

Doubling the diameter of a pipe increases its capacity four times. Friction of liquids in pipes increases as the square of the velocity. See table of “Friction of Water in Pipes,” on page 152.

The mean pressure of the atmosphere is usually estimated at 14.7 lb. per square inch, so that with a perfect vacuum it will sustain a column of mercury 29.9 in. or a column of water 33.9 ft. high.

A table showing the quantity of water in imperial gallons, delivered by a pump at each stroke of the engine, will be found on page 94, in the chapter on the drainage of mines.

PUMPING ENGINES.

	2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	12 in.	14 in.	16 in.	18 in.
5	3'3	0'84	0'31	0'12
10	13'0	3'16	1'05	0'47	0'13
15	28'7	6'98	2'38	0'97
20	50'4	12'3	4'07	1'66	0'42
25	78'0	19'0	6'40	2'62	0'21
30	...	27'5	9'15	3'75	0'91
35	...	37'0	12'4	5'05
40	...	48'0	16'1	6'52	1'60
45	20'2	8'15
50	24'9	10'0	2'44
55	56'1	22'4	5'32
60	39'0	9'46
65	14'9
70	21'2
75	28'1
80	37'5
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CHAPTER VII.

ROCK DRILLING MACHINERY.

Percussion Drills—Requirements of a Good Drill—Use of Steam—Compressors—Heating—Sources of Loss—Law of Volumes and Pressures—Variations in Atmospheric Pressure and Effect on Compressing Machinery Air Mains—Loss due to Friction—Air Leakage—The Daw Rock Drill—The Schram Drill—The Sergeant Tappet Drill—The Ingersoll-Sergeant Auxiliary Valve Drill—The Optimus Compound Drill—Dimensions of Various Drills.

THE application of machinery to rock drilling has been in course of perfection during the past one hundred and fifty years, and, as is usual, the honour of being the original inventor is claimed by many men of various nations, while the subsidiary inventors and improvers have been still more numerous. We, however, have to consider the rock drill as it exists to-day, and to describe a few of the forms most frequently in use, without, however, asserting that they are the most perfect.

Rock drilling machines may be grouped into two great classes—first, those that bore by percussion combined with a comparatively slow rotation of the drill ; and, secondly, those that drill by constant pressure and rotation, of which the well-known Diamond drill described on page 200 is the best example.

The principle of the percussive drill is that of a steam cylinder, to the piston rod of which a boring tool is attached. The rapid strokes of the piston, which is usually driven by compressed air, though steam may be used, strike the boring bit against the rock, and so gradually cut a hole the same as in hand drilling.

The variations in the different patents and inventions consist of special arrangements by which the chief end is accomplished, as

ROCK DRILLING MACHINERY.

or turning the drill around as it works and in lengthening mine, or so altering its position, as to adapt the blows to increasing depth of the hole.

Requirements of a good rock drill are stated concisely as by André, in his work upon coal mining.

A machine rock drill should be simple in construction, and every part.

should consist of few parts, and especially of few moving

should be as light in weight as can be made consistent with first condition.

should occupy but little space.

The striking part should be relatively of great weight, and strike the rock directly.

No other part than the piston should be exposed to violent

The piston should be capable of working with a variable stroke.

The sudden removal of the resistance should not be liable to cause injury to any part.

The rotary motion of the drill should take place automa-

The feed, if automatic, should be regulated by the advance motion as the cutting advances.

It may be added that the best rock drill is equally good in its recovery as in its blow—that is, it should have as much power to get the bit out of a bad hole as it has force to drive it into a hole.

For carrying purposes the drill is mounted upon a tripod, to which heavy weights are attached in order to give the necessary rigidity; and for these drills which are comparatively small, boiler, steam is frequently used.

It of course be also used for driving tunnels underground, but there are difficulties in the way of conducting it in the pipes, the enormous loss from condensation, and also from the exhaust steam which must be condensed, or, otherwise, the tunnel would be too hot to work in, and which also does not contribute, as the exhaust air, to the ventilation. The longest tunnel which

has been driven by the use of steam for the drills is probably that known as the Magna Charta at Tomichi, Colorado, where the $1\frac{1}{4}$ ins. steam pipes ran for 3000 ft. from the boiler to the drills in the face of the tunnel. As the work progressed the boiler pressure was gradually raised from 80 to 100 lb. per square inch, but after 3000 ft. an air compressor driven by water-power was put in, in the place of the steam and boiler.

COMPRESSORS.—Compressed air can be conveyed in pipes for several miles, and still be capable of performing very useful if not economical work. As a means for the transmission of power, whether to rock-drills, pumps, or hauling-engines, it possesses defects of a serious character; and these arise from various causes, one of the principal of which is the heat accumulated during the act of compression. The reason for the resulting loss will be readily understood when we know that heat acts expansively upon air; in other words, a volume of air will exert less pressure upon the sides of a containing vessel when at a temperature of 10° than when at 20° .

This being true, the piston of a compressing engine is met both by the natural resistance of the air to compression and by the increased resistance due to the expansion by heat. To illustrate this, suppose we have one cubic foot of air at atmospheric pressure, and at a temperature of 60° , and then compress this air to 58.8 lb. per square inch, the volume of the air will be reduced to .3194 of a cubic foot, and its temperature will have risen to 369.4° , making an increase of 309.4° .

The all importance of supplying the compressor with air at as cold a temperature as possible, from outside the engine room, and of keeping the compressing cylinder cool by means of a constant stream of cold water circulating through the water jacket, is very evident from the above example. In some machines a spray of cold water is injected into the cylinder in order to cool the air more rapidly, but this system is not to be recommended, both because it rusts the inside of the cylinder, and also because it moistens the air, which, on expansion, when leaving the exhaust ports of the drills, freezes and clogs the machine with ice.

Compressed air occupies considerably less volume than free or atmospheric air, and, in this particular, follows Mariotte's law,

ROCK DRILLING MACHINERY.

s that the pressure of any gas varies in the inverse ratio to
me, the temperature remaining constant, so that if

P = the original pressure.

P' = „ new „

V = „ original volume.

V' = „ new „

$P' : P = V : V'$

ex. 1.—What vol. V' will 100 cubic ft. of atmospheric
air at the sea level averages about 15 lb. per square inch)
, when compressed to 60 lb., or 4 atmospheres, effective
pressure (5 atmospheres, absolute).

$$\begin{aligned} V' &= \frac{P \times V}{P'} \\ &= \frac{15 \times 100}{60 + 15} = 20 \text{ cubic ft., or} \end{aligned}$$

1/5th of the original volume. So that approximately the volume
of compressed air is equal to the original volume, divided by the
number of atmospheres (absolute) to which it has been compressed.

ex. 2.—Required the size of compressor to supply air at
effective pressure, to work two 3-in. drills.
required per minute—

$$\begin{aligned} 15 \times 2 &= 30 \text{ cubic ft. at 60 lb.} \\ \text{or } 30 \times 5 &= 150 \text{ „ of free air at} \end{aligned}$$

atmospheric pressure would be required per minute to work both
drills simultaneously.

Required the piston speed at 300 ft. per minute.—

$$\begin{aligned} \text{Area of cylinder} \times 300 &= 150 \\ \text{„ „} &= 1/2 \text{ sq. ft.} = 72 \text{ sq. in.} \end{aligned}$$

This represents a cylinder diameter of 9 1/2 in. to which the nearest
compressor would be 10 in. diameter.

A smaller plant than a 10 in. compressor and two drills is very
rarely employed, and would not be economical.

ex. 3.—Required the size of compressor to supply air at
effective pressure to work six 3 1/2-in. drills.
required per minute—

$$\begin{aligned} 20 \times 6 &= 120 \text{ cubic ft. at 60 lb. pressure,} \\ \text{or } 120 \times 5 &= 600 \text{ „ of free air at atmospheric pressure.} \end{aligned}$$

Assuming a piston speed of 350 ft. per minute—

$$\begin{aligned} \text{Area of cylinder} \times 350 &= 600 \\ \text{,,} \quad \text{,,} &= \frac{600}{2.5} \text{ sq. ft.} = 247 \text{ sq. in.} \end{aligned}$$

which represents a cylinder of $17\frac{3}{4}$ in. diameter, the nearest sized compressor to which would be an 18-in.

It would be possible to drive the 6 drills with a 16-in. compressor running a little faster, taking into consideration that seldom more than 5 drills would be working at one time; on the other hand, it would be more economical, and better, in the long run to employ an 18-in. compressor.

A rule by which the volumes of compressed air may be approximately determined from volumes of free air, is to divide by the number of atmospheres. For instance, 60 lb. represent five atmospheres (absolute—that is, taking the atmospheric pressure of 15 lb. into account), 500 cubic ft. of free air divided by 5 = 100 cubic ft. of compressed air, at 60 lb. gauge pressure. This rule gives only approximate results, as the pressure is not always an exact multiple of an atmosphere.

Another most important point which has very considerable practical importance, is that the above rules are based upon the data of sea level, at which the normal atmospheric pressure is 15 lb. per square inch. Most mines, however, are in elevated regions; the atmospheric pressure, therefore, is less, as shown in the following table in column A. In column B will be found the difference in volume, as compared with the volume of air at the sea level, which is taken as being 1.

Pressure at $\frac{1}{4}$ mile above sea level				A		B
				14.02 lb. per sq. in.		7% less.
,,	$\frac{1}{4}$	,,	,,	13.33	,,	11% ,,
,,	$\frac{1}{2}$	,,	,,	12.66	,,	16% ,,
,,	1	,,	,,	12.02	,,	20% ,,
,,	$1\frac{1}{4}$	,,	,,	11.42	,,	24% ,,
,,	$1\frac{1}{2}$	,,	,,	10.88	,,	28% ,,
,,	2	,,	,,	9.88	,,	34% ,,

In practice, approximate determinations of the reduced efficiency of air compressors are made by deducting the percentage of difference between the barometric pressures at the respective altitudes, or by the following rule :—

ROCK DRILLING MACHINERY.

efficiency at the sea level to be 100, then the efficiency for every 1000 ft. of altitude is approximately.

ical difficulty which involves loss of efficiency in is due to the clearance space at the ends of the at the completion of a stroke, is full of compressed re the forward stroke can draw in a new supply of e, this cushion of compressed air must lose its ansion, so reducing the quantity of fresh air, which and compressed. Add to this the leakage of the which allow a certain quantity of compressed air the cylinder from the air receiver, and we see at a percentage must be deducted for loss from the ntity of air which the machine should compress, s, according to the make of the compressor, from t.

—In designing a rock drill plant the greatest care n to make the air pipes of ample size, so as to ssage to the air, which travels within them at a 1 25 to 30 ft. per second. All unnecessary angles uld be avoided, as they add greatly to the fric-, and consequently decrease the pressure, which to the length of the pipe and the square of the

to and including 5 in. diameter, wrought iron is d, with ordinary screwed sleeve connections. The supplied with flanges, the joints being made with rubber rings. Pipes with flanged joints are more use in shafts where the screwing of sleeve-jointed e of trouble and delay.

pipes up to $1\frac{1}{4}$ in. diameter are tested to a pressure quare inch, while the larger are tested to 500 lb. 1. Great care must be taken that the joints are ht, as the amount of loss even from a pinhole is le.

ig table will show the loss in air pressure due to pipes, and is calculated for each 1000 ft. of pipe r lengths of pipe the loss is in direct proportion :—

INSIDE DIAMETER OF PIPE IN INCHES.

Velocity in ft. per Second.	1-in.		2-in.		3-in.	
	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.
3.28	6	0.143	23	.079	48	.046
6.56	12	0.640	46	.305	96	.212
9.84	18	1.450	69	.721	144	.488
13.12	24	2.560	93	1.256	193	.838
16.40	29	3.930	116	1.964	241	1.317
19.68	35	5.420	139	2.712	289	1.807
26.24	47	10.240	185	5.026	386	3.351
32.80	59	15.730	232	7.856	480	5.270
	4-in.		5-in.		6-in.	
	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.
3.28	86	.035	134	.028	193	.023
6.56	172	.152	268	.153	386	.104
9.84	258	.361	402	.290	579	.244
13.12	343	.628	537	.512	772	.419
16.40	429	.981	671	.786	965	.659
19.68	515	1.355	805	1.084	1158	.904
26.24	687	2.512	1073	2.049	1544	1.675
32.80	859	3.927	1342	3.146	1931	2.634

Example.—An air compressor furnishes 386 cubic ft. of free air per minute at a pressure of 60 lb. per square inch in the receiver. If this air is used at the end of a 3-in. pipe 1000 ft. long, the loss due to friction will be $3\frac{351}{1000}$ lb. If the same volume of air were supplied by the same compressor at the same pressure and passed through a 6-in. pipe 1000 ft. long, the loss would be only $\frac{104}{1000}$ lb. ; thus illustrating the importance of using pipe of large diameter. If the pipe were 500 ft. long the loss would be one-half as much ; if 2000 ft., it would be double as much, and so on for any length.

Elbows and irregularities in pipe increase the friction above the figures given in the table.

The foregoing table represents only the loss by friction in the pipe. There is a further slight loss due to the friction of the air with itself at the mouth of the pipe when it leaves the receiver.

ROCK DRILLING MACHINERY.

leakage.—All leaks in compressors or valves, air receivers should be strictly guarded against for the sake of in the running of compressed air and steam apparatus. are fully as expensive as steam leaks, and should be as stopped. Too many miners think that an air leak is of consequence, but in reality it should never be allowed, re needed for actual ventilation. When it is remem- t air issues from a leaky joint in a pipe at a velocity of ft. per second, at 60 lb. pressure, the waste of power age will become apparent.

new Rock Drill.—Rock drills may be roughly divided classes, according to the manner in which their slide actuated, which may be either by the operation of the m alone, by means of special openings in the body of , or by a mechanical action due to the main piston some arrangement of levers, which in turn work the slide which an example is given on page 166.

cal of the former, I purpose describing the Daw rock h was first introduced at the International Exhibition g and Metallurgy in London in 1890, where it obtained st award, both for its compact construction and the f its boring, which attained the speed of $7\frac{1}{2}$ in. per a block of granite.

ill is shown in the sectional illustration, fig. 106, and meter machine is only 33 in. long over all, although its feed is 24 in.,—a great feature when the awkward and nature of the places in which these machines have to onsidered.

inished length is due to the short piston which is used the long one grooved with air passages, or arranged to tappet valves necessary in the ordinary form of drill. ness of the piston in its turn is a consequence of the ew and very simple valve, which is the invention of the nd which, in connection with two air passages formed e leading feature of the machine.

ide valve takes the form of a double ram piston turned to fit the two small cylinders, one at each end lve casing, as shown in the illustration, and is provided

with certain annular grooves and air passages for controlling the admission of the air or steam to the main cylinder. It is shot over by direct pressure in the same direction as that in which the main piston is travelling, and is automatically held and locked against its seat until released by the air pressure at the moment of making the return stroke, so that it is impossible for the valve to drop by gravity, no matter in what position the drill is worked, and all mis-strokes and loss of air are thus prevented.

It will be seen by examination of fig. 106 that, in addition to the valve pistons for controlling the passages leading from the cylinders in which such pistons work to the main cylinder, two additional pistons of larger diameter are provided, and form one with the valve pistons; and it is between these supplemental

FIG. 106.—SECTION OF THE DAW DRILL.

pistons that the valve for controlling the supply and exhaust of the main cylinder is carried. An annular groove is formed between each of the supplemental pistons and of the valve pistons, and each of the former works in conjunction with a cylinder opening into the valve chest, but which, when its piston enters the same, is cut off therefrom; in which case the annular groove and the additional port or passage place the rear of the piston directly open to exhaust, while when the piston has left its cylinder the live air or steam from the valve chest acts upon the rear of such piston, and forces the other supplemental piston into its cylinder, and firmly against the end thereof, such cylinder being then directly open to exhaust through its additional passage and the annular groove above referred to.

ROCK DRILLING MACHINERY.

When the supplemental piston leaves its cylinder the admission passage has been previously closed by the valve piston, so that the live air or steam cannot pass from the valve chest to the admission passage, which is open to exhaust.

The valve is actuated by direct pressure, and when shot over automatically locked and held against its seat until released by the pressure at the moment of making its return stroke; in direct ratio to the pressure of motive fluid it is cushioned at the end of its travel and brought to rest without shock or wear. The supply ports, which, it will be seen, are short and direct,

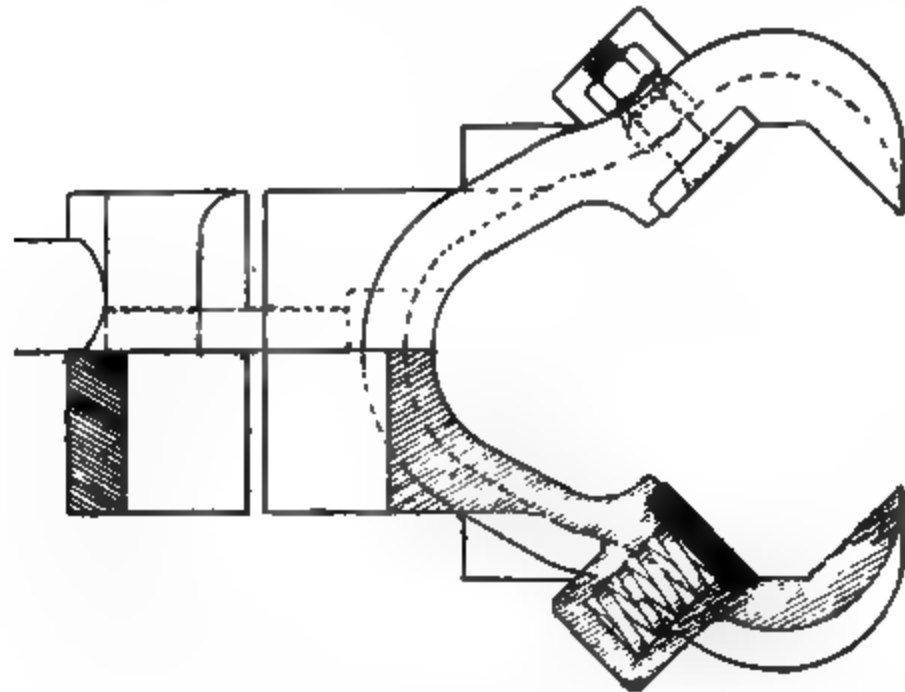


FIG. 107.—SECTION OF DAW'S ROCK DRILL CARRIAGE.

When fully open, securing the highest speed with heaviest work. We should add that the piston is fitted with a special packing, so that loss of air by leakage past the piston is prevented, and the full efficiency of the drill maintained so long as it is in use.

One of the most fruitful sources of trouble in rock drills has been the wear on the cradle guides, feed screw and nut, caused by the slight movement due to the incessant shocks of the recoil of the drill. This has been overcome in one of Messrs. Daw's recent inventions, and in their new cradle, with which all their drills are now supplied, the wear is automatically taken up.

Sufficient resistance is at the same time automatically offered to the free movement of the drill in the cradle guides, so as to relieve the feed screw and nut of the shock of the recoil of the drill, and thus the cause of the great strain on, and wear of, the feed screw and nut is removed. An inspection of fig. 107, which gives an end view of the Daw cradle, and is partly in section and partly in elevation, will show that this desirable object is most simply brought about. On each of the lower guides a recess is made to receive a steel liner, which is held in position by bolts at each end of the cradle. Springs fitting into suitable recesses formed in the cradle are inserted below the liner. When the drill is placed in the guides the bolts holding the liner in position are loosened, and the springs cause it to automatically take up all wear from the movement of the drill in the guides. Further, the springs are given sufficient tension to cause the liner to force the V projections on the drill between it and the top guides of the cradle just strongly enough to give

FIG 108.—SECTION OF THE SCHRAM ROCK DRILL.

ROCK DRILLING MACHINERY.

ent friction to the free movement of the drill when running, allowing it to be readily fed forward by the feed screw. relieves the feed screw and nut from the shock of the recoil, almost entirely from all wear. The tension of the springs their limits can be controlled by loosening or tightening bolts holding liners in position.

3 SCHRAM ROCK DRILL.—The mechanism of the Schram drill is shown in fig. 108, and is typical of those drills in the motion of the slide valve is controlled by the main without the intervention of tappets.

erring to fig. 108, *i* is the main piston, *ii* the slide-valve and slide, *iii* the rotating movement with its piston. In other forms of the machines, however, the rotating movement is actuated by a ratchet and pawl instead of the arrangement here indicated.

The working of the machine is as follows :—When the piston, *d*, is in the position shown, and on cock being opened the air or steam enters the cylinder, *c*, through the port, *b*, and, pressing on the lower end of the piston, *d*, forces it backward, causing the back-stroke. As soon as the piston, *d*, has passed the port, *e*, air enters through that port into the small cylinder, *g*, in the slide box. At this moment, when the air presses upon the upper end of the piston, *f*, the cylinder, *k*, is in communication with the outlet, through the port, *i*, and the circular hollow in the piston rod, *r*; consequently, the slide piston with the shell is moved downwards, and the passage, *h*, is opened for the admission of air from the box, whilst the lower end of the cylinder through the port, *l*, communicates with the outlet, *s*. The air now entering, *c*, through the opened port, *h*, presses on the upper end of the piston, *g*, and it forward, and thus causing the drill, carried in a socket at the extremity of the piston rod, to strike with the impetus of its own weight and all the power of the compressed air against the rock. As soon as the piston, *d*, has passed the port, *i*, air enters through it into the cylinder, *k*. At this moment the cylinder, *g*, communicates with the outlet, *s*, through the port, *e*, and the circular hollow, *r*, in the piston rod, and the side piston with the slide is moved back into the same position. Meanwhile the piston, *d*, has completed its stroke; the cylinder, *c*, is, through the

passage, *k*, in communication with the outlet, *s*; and the compressed air again rushing through the re-opened passage, *b*, causes the action just described to be repeated so long as the supply of motive power is kept up.

It is an important feature of this machine that the slide rod, *f*, is made in the form of a double spindle valve. By this method of construction it remains in position, without any recoil, until the piston, *d*, has made the greater part of its stroke.

As, in some varieties of rock, it happens that the drill often sticks fast, there is a reversing rod, *l*, to suddenly reverse the slide and pull the drill out of the hole. With careless workmen it would frequently happen that the piston would strike against the lower cylinder cover; therefore an air cushion is placed at the lower end of the cylinder.

In addition to this there is an iron ring and an indiarubber washer (exchanged for one of wrought iron when steam is used), with the object of moderating the violence of the shock such blows, inadvertently permitted, would cause.

In order that the hole drilled may be perfectly round, it is necessary that the cutting tool should partially rotate at each backward stroke, so that its cutting edge shall every time strike the rock in a fresh place; but in order to avoid loss of power it must make its forward stroke without rotating.

For this purpose a twisted bar, *o*, is employed, connected in the new drills with a ratchet wheel at *p*, which is free to rotate in one direction, but is held by a pawl engaging in its teeth, and so prevented from turning in the opposite. When the piston makes its forward stroke the ratchet allows the twisted bar and ratchet wheel to make a partial rotation; but on the return stroke the pawl retains the ratchet wheel, and the piston is bound to work in the grooves of the twisted bar, and so give itself a slight twist round, causing the bit to strike in a new place on the next forward stroke.

This drill has acquired a large reputation, and the latest use to which it has been put is the drilling of the holes in the rocks which protruded through the bottom of H.M.S. *Howe*, sunk in Ferrol harbour, previous to their being removed by blasting.

ROCK DRILLING MACHINERY.

GEANT-TAPPET DRILL.—In all the earlier rock drills the valve was moved by mechanical means, and received the motion of the tappet drills. It is unnecessary to illustrate all the different valves that have been conceived for this purpose; it will be sufficient to think, to illustrate the most improved and simplest tappet motion as used in the Sergeant-tappet drills in which the steam is wet and the rock reasonably soft. It will work anywhere with steam or air, but for work in the Ingersoll-Sergeant drill, with an independent valve, as shown on page 167, is said to be more efficient and more

efficient. The movement of the tappet valve is shown in fig. 109. The valve and the rocking bar are all in one piece, and the movement is effected by the inclined planes of the piston

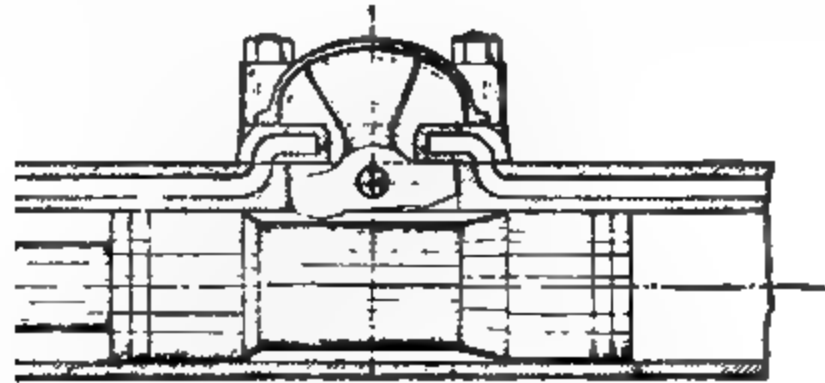


FIG. 109. SERGEANT-TAPPET VALVE.

in contact with the end of the rocking bar, and so altering the position of the slide valve, which opens and closes the pressure and exhaust ports in conformity with the position of the piston.

The pressure of the air or steam keeps the valve constantly closed, and, as it is made of the best materials, the wear is reduced to a minimum.

The various sizes and particulars of this drill will be found in the comparative table, page 171, together with those of the Eclipse drill by the same company.

These drills manufactured by the Ingersoll-Sergeant Drill Company, from the "Old Reliable Eclipse" down to the latest Auxiliary, have been before the mining public for so many years in such large numbers—there are, I believe, over 10,000 in

use—that most mining men have come into either theoretical or practical contact with them. I have, therefore, confined my description to the newer and less-known types, which embody all the modern improvements.

THE INGERSOLL-SERGEANT AUXILIARY VALVE DRILL.—The special feature of the Ingersoll-Sergeant drill, as now made, is that the main valve is operated through an auxiliary valve, this latter receiving its motion from the piston and acting, so to speak, as a trigger to the main valve.

The arrangement will be understood by reference to the section of the drill given in fig. 110. The auxiliary valve is made of light steel in the form of an arc of a circle, and in consequence is easily moved by the piston at the end of its stroke. The subsidiary thus acts as a slide valve to the main valve, which is moved by the air pressure in accordance with it, and so in its turn regulates the supply of air to the main piston.

The drill strikes an uncushioned blow. The main slide valve is held in such a position by the action of the auxiliary that, while the piston carrying the cutting tool is moved towards the rock, the full pressure of air or steam acts upon it until the blow is struck, at which moment the valve immediately reverses it.

The full pressure thus being kept up until the last moment, the air is not used expansively, and as the backward stroke is an equivalent of the forward, the power of the machine to withdraw the drill from tight or crooked holes is exactly equal to its power of striking a blow; and there is consequently less tendency to get jammed.

In order to avoid breakage from careless feeding, resulting in

FIG. 110.—THE INGERSOLL-SERGEANT AUXILIARY VALVE DRILL.

the front or back end of the cylinder, are used as buffers. These springs are , and are connected with the front head ch a manner that a blow either on the front or back heads is cushioned by the springs and a breakage prevented.

The feeding of the Ingersoll-Sergeant drills, and, indeed, of all drills used in mining or tunnelling, is now effected by hand; but for surface work with large drills making vertical holes an automatic feed attachment is of great value, especially in countries where skilled men for running the drills are scarce, and one man has to look after several machines. These drills, however, are not within the scope of mining proper, and so do not demand a detailed description.

FIG. 111.—THE OPTIMUS COMPOUND ROCK DRILL.

THE OPTIMUS COMPOUND ROCK DRILL.—There are many reasons which prevent the ordinary rock drill from being worked with the same economy of steam or air as is effected in a high-class engine. As a rule, the waste of air is very considerable, varying, of course, according to the numerous devices of different makers for controlling its admission to, and exhaust from, the cylinder. In the Optimus drill, Schram and Co., the compound principle y, and is said to effect a saving of 45 per of any other drill of the same size. machine will be seen in fig. 111, and a lower end of the cylinder is bored out to

a larger diameter than the upper, and the air under pressure used for the forward stroke instead of being exhausted into the atmosphere in the usual manner is conducted to the front end of the cylinder, and, acting upon the increased area of the piston, is utilised for the backward stroke, thus effecting the above-mentioned saving.

This economy in air used at the drill reacts over the whole plant, and permits of smaller-sized compressors, boilers, and piping being used.

Referring now to the sectional drawing, fig. 112, the operation of the machine is as follows:—Assuming the piston and valve, *e*, to be in the position shown in the illustration, the cylinder, *a*, will be in communication with the atmosphere through the ports, *m*, *f*, and *h*. The result of this will be that the piston is forced

FIG. 112.—SECTION OF THE OPTIMUS COMPOUND ROCK DRILL.

forward, and, immediately the piston, *e*, uncovers the small port, *d*, a portion of the compressed air passes into the small cylinder, *r*, behind the valve, *e*; and acting on a larger area than that which is subject to the constant pressure at *l*, and the fact that there is no resistance at the other end of the valve, *e*, owing to the passage, *n*, communicating with the atmosphere, forces the valve, *e*, over to the other end of the valve chest, thereby cutting off the communication with the air under pressure, and placing the cylinders, *a* and *a'*, in communication through the ports, *b* and *m*. Then the air that has acted on the piston, *e*, now passes into the cylinder, *a'*, where it acts on the piston, *g*, of larger area than the piston, *e*, thereby moving the piston backwards to its original position. When the piston, *e*, during its backward stroke passes the port, *d*, the cylinder, *r*, is placed in communication with the

ROCK DRILLING MACHINERY.

through the ports, *d'* and *k*, and the constant pressure on the piston valve, *c*, at *l* moves the said valve over to *n* as shown in the illustration, the air again enters the cylinder, and the action is repeated.

It is seen that the air used for the forward stroke is again used for the backward stroke without in any way impeding the forward stroke, and this, as well as the shortness of the stroke, causes a great saving of motive fluid. The air being constantly admitted to the cylinder, *d*, while the cylinder, *d'*, is in communication with the outlet, causes the piston to give a very powerful blow, which makes this machine more efficient than any other rock drill using considerably more motive fluid. At the end of each backward stroke there is still some air left behind the piston, *c*, which fact has three distinct results, viz. :—

1. It consists in cushioning the piston at each backward stroke, so that no special space for an air cushion is required.

2. The presence of this air pressure causes the space in the cylinder to be more quickly filled up with air at full pressure, so as to give to the piston a more powerful blow.

3. It causes a saving in motive fluid.

In comparison with the weight and price of the ordinary rock drill it may be stated that a 3-in. diameter Optimus with its cylinder weighs 220 lb., and costs £52. A 3¼-in. diameter weighs 250 lb. and a 3½-in. 310 lb., and cost £55 and £60 respectively. The makers claim that whatever can be done with ordinary drills can be done equally well with these compound drills, and that the saving effected in air is at least 45 per cent.

On the other hand it is argued that as a rock drill can never work continuously, and that for at least two-thirds of its time it is lying idle, the operation of starting and removal from one point to another, the saving of air effected by compounding can be but slight. To us, however, that slight as this saving may be, it is of great importance where a large number of drills are in operation, and when steam is employed to drive the compressor.

The drill in most general use for mining purposes has a cylinder 3-in. diameter, and the following are the descriptive particulars of the types of rock drills in ordinary use :—

COMPARATIVE TABLE OF ROCK DRILLS.

171

Name of Drill.	Ingersoll Eclipse	Sergeant.	Daw's.	Optimus Compound	Schram	Adelaide.	Sergeant- Tappet
Letter Indicating Size	D	D	I				D
Diameter of cylinder	3 in. 6 in.	3 in. 6½ in.	3 in. 5½ in.	...	3 in. 6 in.	3 in. 5 in.	3 in. 6½ in.
Length of stroke	48 in.	50 in.	35½ in.	...	42 in. 1 in.	43 in.	50 in.
Extreme length of drill, from end of crank to end of piston	1 in.	1 in.	...	...	185 lb. 220 lb.	177 lb. 195 lb.	236 lb. 265 lb.
Diameter to supply inlet.	27½ lb.	236 lb.	230 lb.	220 lb.	...	...	...
Weight of drill unmounted	155 lb.	165 lb.	130 lb.	...	675 lb.	555 lb.	716 lb.
Weight of tripod, without weights	742 lb.	716 lb.	...	...	350 lb.	...	...
Shipping weight of drill, tripod, and weights, complete	325	325	700	...	550 lb.	...	...
Approximate strokes per minute with 60 lb. pressure at drill	550 lb.	150 lb.	175 lb.	...	28 in.	...	...
Approximate weight of blow delivered on the rock at each stroke	24 in.	24 in.	...	...	80 ft. 1 to 15 ft.	1½ to 1½ in. 1½ to 1½ in.	1 to 10 ft. 1½ to 2½ in. 1 to 1½ in.
Depth drilled without changing bits	60 ft.	70 ft.	1 to 14 ft.	...	...	...	...
Done per 10 hours, in granite, downing time lost in setting drill and at hole each machine will drill easily	1 to 2 in. 1½ to 1 in. 1½ to 1 in.	1 to 14 ft. 1½ to 2½ in. 1½ to 1½ in.	1 to 2 in. 1 to 1½ in.	...	...	...	...
Diameter of holes drilled, as desired	1 x 5 in.	1½ in.	1 to 1½ in.	...	8 in.	...	...
Diameter of drill steel used	6	7	...	...	235 lb.	...	...
Set of steels to drill holes in	139 lb.	225 lb.	...	...	4 h.p. 1 in.	...	8 h.p. 1 in.
one set steels to drill vertical	10 h.p.	8 h.p.	...	...	22 in.	20 in.	24 in.
stated	1 in.	1 in.	24 in.	...	450.	440	450
Best size of boiler to give plenty of steam at high pressure	275	275	24 in.	...	450.	...	...
team 100 to 200 ft.	450	450	...	...	450.	...	...
tripod or column	8325	8325	...	...	3½ dia.	...	...
	4½ in.	4½ in.	4 in.	...	120 lb.	...	...
	280 lb.	280 lb.	140 lb.	...	...	...	...

Speed of Drilling.—The rate at which a tunnel can be driven by means of rock drills may be safely taken at double the speed of handwork. I find from the records of the progress made in driving the heading (8 ft. \times 20 ft.) of the Vosburg tunnel on the Lehigh Valley Railway, through a uniform hard grey sandstone, that by hand drilling the average progress was 67 ft., while that of the machine drilling was 173 ft. per month. There can be no question that, for driving and sinking, machine drills are far superior to hand labour both in speed and economy. For stoping, however, except in wide stopes, the difference between the two systems is not so marked, as it is difficult to manœuvre a machine in places where a man can hardly find room to work with a single hand hammer.

CHAPTER VIII.

ROCK DRILLING MACHINERY (continued).

Air Compressors—Compressing Plant—Supporting Columns and Tripods for Drills—Steel Bits and Sharpening Tools—The Working of Rock Drills—Specification of a Rock Drilling Plant.

AIR COMPRESSORS.—The machines for compressing air are now built especially for that purpose, and may be driven indirectly by the power of water, electricity, or steam through the intervention of belting or gearing, or directly by steam, in which case

FIG. 113.—SCHRAM'S AIR COMPRESSOR DRIVEN BY BELTING.

the air compressing and the steam cylinders are usually fixed in one line, tandem fashion, with a piston rod common to both.

Of the former type fig. 113 is an illustration, and may be driven by a belt from a portable engine, or from a line of shafting, or

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PLAN AND ELEVATION OF AIR COMPRESSOR, AIR RECEIVER AND BOILER, SHOWING PIPE CONNECTIONS AND
AUTOMATIC AND ADJUSTABLE REGULATOR AND UNLOADING DEVICE FOR AIR AND STEAM

See,
and

The small pipe, 7, between the receiver and the compressor is part of the automatic and adjustable unloading device for air and steam, by means of which the speed of the engine is regulated according to the pressure of the air in the receiver. When the pressure of the air exceeds the desired point in the receiver the steam is automatically throttled, and only enough admitted to keep the engine turning round, and another function of this device is to prevent the compressor from stopping or getting on

TABLE GIVING SOME OF THE MOST IMPORTANT DIMENSIONS OF THE COMPRESSING PLANT SHOWN IN FIGS. 115 TO 116.

DESIGNATION.	SIZES.							
	10 x 12 in.	12 x 14 in.	14 x 18 in.	16 x 18 in.	18 x 24 in.	20 x 24 in.	22 x 30 in.	24 x 30 in.
Size of steam cylinder	10 1/2 x 12 in.	12 1/2 x 14 in.	14 1/2 x 18 in.	16 1/2 x 18 in.	18 1/2 x 24 in.	20 1/2 x 24 in.	22 1/2 x 30 in.	24 1/2 x 30 in.
Size of air cylinder	2 1/2 in.	3 in.	3 1/2 in.	4 in.	5 in.	5 in.	5 in.	6 in.
Size of steam pipe	3 in.	4 in.	4 in.	5 in.	6 in.	6 in.	6 in.	7 in.
Size of exhaust pipe	3 in.	3 1/2 in.	3 1/2 in.	4 in.	5 in.	5 in.	5 in.	6 in.
Size of air pipe	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.	1 in.	1 in.	1 in.	1 in.
Size of water circulating pipe	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.	3 1/2 in.
Size of drip pipes	1 1/2 in.	1 1/2 in.	1 1/2 in.	1 1/2 in.	1 1/2 in.	1 1/2 in.	1 1/2 in.	1 1/2 in.
Number of revolutions per minute	160	155	120	120	94	94	75	75
Indicated horse-power of boiler	30	40	55	70	130	130	155	200
Weight of heaviest piece (bed-frame)	975 lb.	1,650 lb.	2,900 lb.	2,900 lb.	4,950 lb.	4,950 lb.	7,000 lb.	7,000 lb.
Weight of flywheels on shaft	1,050 lb.	2,550 lb.	3,125 lb.	3,700 lb.	6,100 lb.	7,200 lb.	8,500 lb.	10,500 lb.
Weight of complete compressor	5,500 lb.	7,400 lb.	10,800 lb.	12,000 lb.	20,050 lb.	21,400 lb.	29,000 lb.	34,500 lb.
Length over all	10 ft. 10 in.	11 ft. 3 in.	13 ft. 9 in.	14 ft. 0 in.	16 ft. 10 in.	17 ft. 2 in.	20 ft. 6 in.	20 ft. 6 in.
Length of bed plate	8 ft. 0 in.	9 ft. 7 in.	11 ft. 9 in.	11 ft. 9 in.	14 ft. 7 in.	14 ft. 7 in.	17 ft. 2 in.	17 ft. 2 in.
Width over all	2 ft. 10 in.	3 ft. 7 in.	4 ft. 1 in.	4 ft. 2 in.	5 ft. 2 in.	5 ft. 2 in.	5 ft. 10 in.	5 ft. 10 in.
Height above foundation	2 ft. 7 1/2 in.	3 ft. 3 in.	4 ft. 0 in.	4 ft. 2 1/2 in.	5 ft. 0 in.	5 ft. 3 in.	6 ft. 0 in.	6 ft. 0 in.
Diameter of flywheels	3 ft. 4 in.	4 ft. 2 in.	5 ft. 0 in.	5 ft. 6 in.	6 ft. 6 in.	7 ft. 0 in.	8 ft. 0 in.	8 ft. 0 in.
Diameter of shaft	4 in.	5 in.	6 in.	6 in.	7 in.	7 in.	8 in.	8 in.

ROCK DRILLING MACHINERY.

re, which it is liable to do when working at a slow d.

ie air cylinder is surrounded with a water jacket, through h a constant stream of cold water should be kept flowing.

ie air receiver is fitted with a safety valve and a pressure e. This latter is placed for convenience close to the steam e, g, on the boiler side, so as to be well in view of the



FIG. 117.—SINGLE SCREW COLUMN FOR SMALL DRIFTS AND SHAFTS.

ne-man. The air pipes are connected to the receiver at 10, below them is a blow-off cock, through which any water h may have condensed is driven off.

he receiver may be made of an old boiler, provided it will stand pressure. It should be placed as near the compressor as possible; but if a long length of pipe intervenes between the receiver the drills, it will be found advantageous to put another small iver as near the main junction for the drills as is convenient.

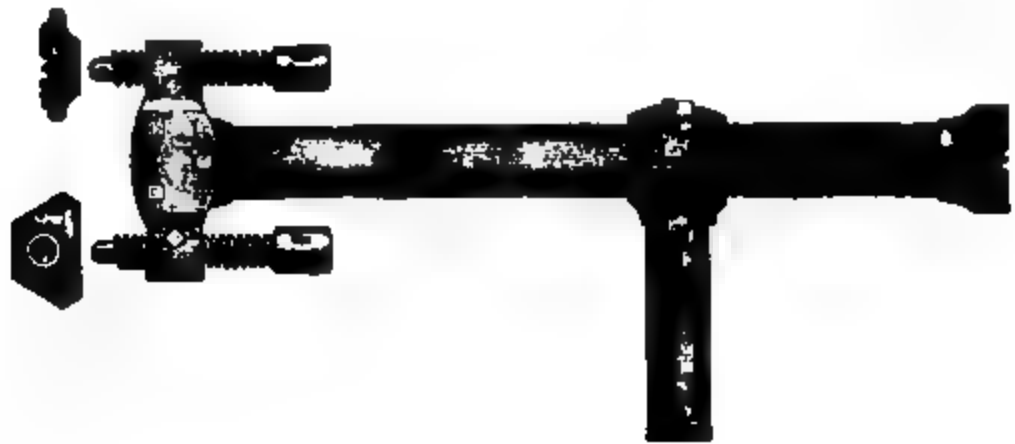


FIG. 118.—DOUBLE SCREW COLUMN WITH ARM.

lthough the type of the compressing plant varies but little rding to the different makers, the general dimensions differ ely with the amount of duty required from it.

or very large permanent installations the compressing cylinders attached in the rear of those of a high-class engine, such . Corliss compound condensing, when, of course, a greater omomy of working can be attained.

SUPPORTING COLUMNS, TORPIDS, AND CARRIAGES.—The tunnels or levels ordinarily used in mining are but small, and the space available for machinery and the handling of the various appliances is very limited.

For this reason the supports upon which the rock drills are fixed



FIG. 119.—CLAMPS FOR INGERSOLL DRILL.

must, as a general rule in mining, be strong, but light and portable, in order that they may be readily removed previous to each blast.

The support in ordinary use is a light steel column, as shown in fig. 117, fitted with a lengthening screw, by which it is tightened up either horizontally or vertically across the tunnel, a block of wood

FIG. 120.—NEW PATTERN CLAMP, USED FOR HOLDING THE SERGEANT DRILL UPON THE ARM OR COLUMN.

being always placed between the ends and the rough, uneven surface of the rock.

In tunnels of large sectional area the double-screw column, fig. 118, is used with the drill mounted on the arm. In small tunnels and shafts the single-screw column, however, is preferred, the drill being mounted directly on the column by means of the clamp, fig. 119, or the new patent Ingersoll-Sergeant clamp, fig. 120, in which the swinging jaw is brought to bear

The weight of such a tripod, without its weights, is, for a 3-in. drill, 130 lb., and the price, including the weights, £15.

For the driving of tunnels of large section, such as railway tunnels, a special form of carriage support is used, such as that illustrated in fig. 122, which was designed by Mr. Richard Schram, M.I.C.E., to carry four of his drilling machines for use in driving $2\frac{1}{2}$ miles of tunnel in 1888 on the Khwaja-Amran branch of the Quetta Railway. The carriage carries two stretcher bars, each of which supports two drilling machines, the arrangement of the carriage and bars being such that trucks for the removal of *débris*, etc., can be run right through it, so that it is unnecessary to provide any sidings in which to run the carriage when the removal of spoil becomes necessary. This arrangement has the further advantage that the drilling machinery can be brought up to the working face before all the *débris* has been removed, thereby economising time. In cases where timbering is necessary, and the stretcher bars have to be lowered to clean up, arrangement is made whereby these, with their machines, can be turned back down on to the carriage. The small receiver shown on top of the carriage is for the distribution of air, and it has two inlets and four outlets, corresponding to the number of drills. The tanks shown on each side are the water injectors, the injection being effected by admitting air under pressure above the surface of the water. The tunnel for which the machines are designed will be driven not only from each end, but by sinking a shaft midway two additional working faces will be provided, making a total of four points of attack. The four sets of tunnelling plant required have all been supplied by Messrs. Schram, and amount, *in toto*, to eight locomotive type boilers, four air compressors, with their receivers, four carriages of the type just described, and thirty-two rock-boring machines, with all the accessories necessary for opening out the tunnel. In mining proper a tunnel of such large dimensions would rarely, if ever, be undertaken; but I illustrate the method adopted in such cases because men accustomed to the use of rock drills are often drafted from their legitimate sphere of mining to conduct works which come more particularly under the designation of civil engineering.

The drill hole, when the machine is at work, must be kept

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preferred. It cannot be used with percussive drills in hard rock, because the blow is so strong that the edge will not stand. Here is where double edging comes in to advantage; for, having plenty of power behind it, we may distribute that power over two or three edges, and thus gain an advantage.

A straight edge on a marble bit will result either in broken edges or in rapidly dulled edges, and in sticking. It is a curious fact that the point on the edge of a marble bit should not be in the centre, but a little to one side, in order to prevent sticking and to do the best work. The reason for this is seen when it is under-

Marble. Sandstone.
FIG. 123.—ROCK DRILL BITS.

stood that the drill, in turning around after each blow, would, were the point in the centre, shape the bottom of the hole like a cone, while, with the point to one side, as in fig. 123, the shape is that of a truncated cone, which offers less chance to stick. The edge might be curved instead of tapering to a point, but the taper is preferred because more readily sharpened. The advantage of a taper or a curve is that it distributes the work more evenly.

A straight edge, when used for hole drilling, brings most of the work upon the outside points of the bit. These points turn around through the largest circle, that which limits the diameter of the hole; and, besides, they have to break up the stone at the wall where it offers the greatest resistance. The taper or curve eases this condition of things by changing the bottom of the hole so that it has no sharp corner.

The tapered single-edge bit does remarkable work in marble

ROCK DRILLING MACHINERY.

ing, and has been frequently timed while drilling holes stally at the rate of 12 and 13 in. per minute, $1\frac{1}{4}$ in. in er, records of 350 lineal ft. of hole, all in holes of about 1 depth, having been put in horizontally in one day of rs.

re the marble or limestone is soft, the edge of the bit be sharp, and in proportion as the stone is harder, the hould be less acute, for the percussive drill, to do the best should strike with its full force ; this it cannot do in hard ith a single-edge bit of acute taper.

lstone has a singular effect upon drill bits. Though sand- are usually soft, the bits cannot be finely pointed, but on ntrary should be flattened. A bit with a knife edge, when 1 sandstone, will have its edge sharpened like a razor, the of the bit gradually becoming concave. This is natural, e, as the bit imbeds itself in the grit of the rock, it is l as though on a grindstone. The stone is not usually ough to dull the sharp line of the edge, so that the more t is used the sharper it gets. It cannot, however, be used ong, because the points or outside ends of the bit become ed and dulled, and, what is a still greater objection, the become tapered. All this arises from the hard work and eat rubbing experienced at the walls of the hole.

: most successful sandstone bit is undoubtedly that with the lge, shown in fig. 123. This bit is nothing more than a ed-out piece of steel with no more edge to it than there is ide of your finger. It is sometimes called the "stub" bit. imensions of this bit cannot be given that will apply in all but the most popular dimensions are about $1\frac{1}{2}$ in. length ; and from $\frac{3}{8}$ to $\frac{5}{8}$ in. in width. The cutting face should be : and rectangular. This bit cannot be tempered in the mith's shop, because there is too much metal in it, and it ke and crack. It is usual to simply dress it up by heating hammering it to square edges, the chief work having to be upon the outside ends in order to keep them square and gauge. When properly dressed it is thrown into a heap of or on the ground, without even putting it in water, except ps for an instant.

There is so much metal in the sandstone bit that it is not rapidly worn away by the grit. It is, therefore, a common thing to see one of these bits in use for half a day, drilling a great many holes in different places, without having to be sent to the shop. When starting a hole it pounds upon the rock like a bass-drum, and an inexperienced looker-on would naturally suggest a sharper edge.

There is no question about the advantage of the flat bit in sandstone quarries, so far as the blacksmith's work is concerned. It will actually put in a hole faster, and it does it because, when



FIG. 124.--ROCK DRILL BITS.

drilling sandstone, the process is not a chipping but a crushing one. Marble, or any other hard crystalline substance, needs a sharp edge to throw a chip, but sandstone will crush.

PERCUSSIVE DRILL BITS.—Prior to the use of the percussive drill there were few, if any, drill bits, which had much value above that with the single edge. Even in artesian well boring, where the blow is heavy, the single-edge bit has held its place against many patented bits.

The illustrations, fig. 124, show a modified form of single-edge bit in comparison with several other bits which are used with success with percussive drills. The flattened or grooved shape given the

single edge at its centre, is for the purpose of discharging the cuttings. As the centre of any bit performs but little work, it may readily be cut away without reducing the efficiency. The other three illustrations shown herewith are the +, the X, and the Z bits. It may safely be said that, apart from the various forms of single-edge bits, previously described, these three are the only really important bits in use with percussive drills.

The + bit is the most popular percussive drill bit in use. It seems to be a happy medium in that it accommodates both the drill runner and the blacksmith, though we are quite sure that were the blacksmith's wishes not consulted, the X bit would replace it almost everywhere.

Out of several hundred inquiries recently sent out among mining and quarrying men as to which bit was preferred—the + or the X—opinions differed largely, but the weight of evidence was in favour of the + bit.

It may be stated as a general rule that the X bit will do good work in *any kind of rock where the + bit is used*, but the + bit *cannot be used to advantage in some rock where the X bit gives satisfaction*.

Another rule is, that the + bit had better be used wherever the rock will admit, for the simple reason that it is more readily dressed by the blacksmith.

The two bits are very much alike in that they have the same extent of cutting edge, but they differ in that the edges in one case cross at right angles and the other at acute angles. As the bit when at work turns round after each blow it is obvious that in the case of the + it may strike four times in the same place while turning the circle, while with the X it can only strike twice in the same place. A + bit when turned one-quarter of the circle, or 90° , may imbed itself in exactly the same groove that had been made by a recent blow; and if this striking in the same place is frequent, and the rock is soft enough to admit of rapid drilling, the hole will become "rifled"—that is, it will not be round. Any one who has much to do with drill holes knows that a "rifled" hole is a great nuisance. As the X bit has only half as much chance to strike in the same place as the +, it offers only one-half the opportunity to "rifle" the hole. It is a common thing

for percussive drill manufacturers to receive complaints that "the drill will not put in a round hole"; the invariable remedy is to change the bit, and as a general thing the X bit is the thing to use.

At the quarries of the Brainerd Quarry Company, Portland, Conn., a $3\frac{1}{2}$ -in. cylinder steam drill is used constantly, putting in holes about 5 in. in diameter with the X bit. These holes are perfectly round. The + bit has been tried, and has failed. At St. Paul, Minn., several holes have recently been drilled for electric poles, the drill cylinder being 5 in. in diameter, and the holes drilled with an X bit are each 7 in. in diameter.

In the blacksmith's shop the + bit is invariably preferred. In using the dolly the blacksmith finds that by turning it one-quarter it fits the bit, and, owing to the rectangular and uniform construction of the bit, he has no difficulty in keeping it at gauge, while with the X he must turn his dolly one-half the circle, and in doing so the bit must either be turned round, or he must send his helper on the other side of the steel. It is because of *this very condition of things as illustrated* in the blacksmith's shop, the X bit when turning around in the hole is *less liable to strike in the same place and drills a better hole*. Persons using the + bit and having difficulty with "rifled" holes can try the experiment by simply knocking the flanges of the bit together in the blacksmith's shop while the steel is hot and after it has been dressed. If they find that this bit will drill a more satisfactory hole, they had better throw away their + dolly, and send for an X, the blacksmith to the contrary notwithstanding.

In trap rock, granite, and other uniform rocks the + bit does good work, and drills a round hole because the rock is uniformly hard, and the drilling is consequently slow.

The Z bit, shown in the illustration, is designed and used to a moderate extent in soft rocks, or in work where seams and soft places are found in the line of the hole. This bit is sometimes modified by having the middle edge straight across, thus making an Γ instead of a Z, but there is little preference between the two, and either one is bad enough for the blacksmith to dress.

To summarise, in gneiss and homogeneous rocks free from faults, the ordinary chisel-shaped bit is to be preferred, as it, perhaps, in such rocks, cuts faster than any other shape of bit, and smiths

ROCK DRILLING MACHINERY.

more readily sharpen it. In schistose rocks wherein layers of different hardness, with numerous fissures are encountered, the chisel bit does not answer so satisfactorily, as the drill seeks the material, gets out of line, sticks fast in the holes, and much is lost in extricating them, and unnecessary jar and strain on the machine. In such ground, to obtain the best results from machine drilling, the chisel bit should be replaced by the cross, of which there are two varieties, the + and X, shown in fig. 124. For the softer rocks the cutting edge can with advantage be made Z shaped.

The quality of steel used in the tool bits requires careful selection, as will be readily conceded when we mention that the atmosphere's effective pressure a 3-in. diameter cylinder drill delivers up to 700 or 800 blows, each of 175 ft.-lb. per minute, the best brands of tool steel are required to stand this severe test in hard rock.

The drill bits, according to size of hole to be bored, should be from $1\frac{1}{2}$ in., $1\frac{1}{4}$ in., $1\frac{1}{8}$ in., and 1 in. octagonal or round steel, and must be taken in changing, and that the bit to follow fits and revolves freely in the hole. The borers should be ordered in successively diminishing diameters, and a distance of 6 in. in each successive tool will generally be found sufficient.

The peculiar shaped bits used for rock drilling require the use of special tools in the blacksmith's shop, in order that they can be made and dressed without difficulty.

These tools are shown in fig. 125, and may be purchased ready made for about £2.

PRECAUTIONS FOR WORKING ROCK DRILLS.—The rock drill is the machine above all others which is most subjected to rough treatment; the more so underground, where, because of the bad ventilation and want of space, and also from the inexperienced hands which it is often placed, it gets more knocking about than is the case for any machine not constructed on the soundest model and of the strongest material.

In some kinds of rock the bits are very liable to stick, and then the workman hammers at it or the drill with whatever happens to come handy. A blow from a hammer is the quickest way to lose a drill, and will do no harm to a first-class machine, but

the blow should be given on the drill, and not, as often happens, on the piston rod or the machine itself. One of my own troubles when running rock drills in a mine in the South of France, where the miners are a hot-headed mixture of Spanish and French blood, arose from the men striking the stuffing box of the drill when the bit stuck, often breaking it, accidentally perhaps; but as this involved a delay for changing the machine, it is doubtful whether the damage was not sometimes maliciously inflicted. And in that particular mine it happened, the miners were much against the introduction of machine labour for stoping.

It is difficult to find and train men fit for the work of running a drill. What is wanted is a man of energetic, ingenious turn of

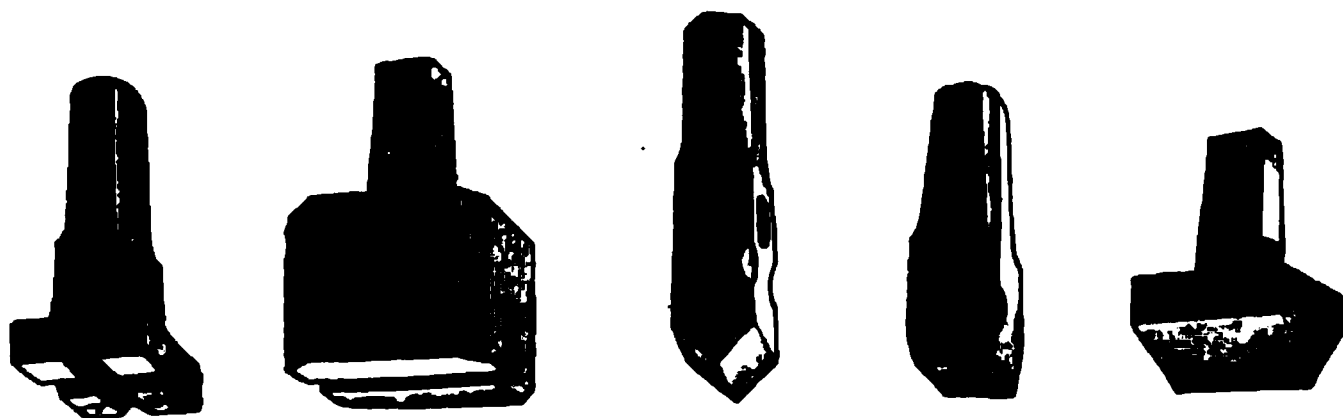


FIG. 125.—SPECIAL SHARPENING TOOLS.

mind, and possessed of much patience, who will take a pride in overcoming the difficulties in the way, and not be happy till he has done so.

At first such a man may lose time by puzzling over the job, but once he gets to know his machine he will not readily be put in a fix; but it is always advisable to have an experienced man to initiate the others at first.

As soon as a drill gets out of repair or refuses to work it should be sent to the surface at once, for it is only loss of time to overhaul it underground, and will lead to the loss of some of the fittings bolts, nuts, etc.

The man who works the machine must also know how to place the hole to the greatest advantage, so as to produce the greatest effect with a minimum of explosive, and then fix the support where it will enable the rock drill to command the greatest number of holes.

In operations for tunnelling, when several drills are run on a

carriage, and rapid advance is the primary consideration, it is best to place the holes on a regular system, in which case electric blasting should also be adopted. Fix the mounting firmly and securely, and if the tripod is to be used with a small hand drill and hammer, notch in the rock a place for each leg. Never omit this, otherwise the vibration will cause the tripod to travel, and thereby bring the borer out of line with the hole, necessitating probably a restart, followed generally with dire abuse on both drill and tripod, when the fault is solely due to the omission of a simple and obvious precaution on the part of the operator. If the column or stretcher bar is to be used, place a block of wood between the rock and one end of the mounting bar, as shown in fig. 117; a block, however, between each end of the bar and the rock is to be preferred. Fix the bar firmly and rigidly between the walls by the jack-screw. Having secured the column in the required position, place the rock drill on it, as shown in the illustration, set the machine to the desired position, and secure it by the cap and bolts provided for that purpose; then square off the rock where the hole is to be placed at right angles to the travel of the borer. This, especially in hard and fissured rock, should be carefully attended to, otherwise the jumper under the heavy blow will on striking the rock glance aside and not cut down the inner edge of the hole in line with the travel of the borer. This deviation, if unattended to, will gradually carry the bit so much out of line as to waste the whole effect of the blow in friction, whereupon a bit with a smaller cutting surface must be inserted. In fissured and troublesome rock, however, when the drill is allowed to get out of line at the start, it will often cause trouble throughout the whole hole, whilst *a hole well started is half bored*.

Having squared the rock off and everything ready for a start, put in the shortest borer, draw out the piston rod until the piston head strikes the bottom of the cylinder, and screw forward the drill until the borer touches the rock, and then give the feed screw a couple more turns. To fix the borer in its conical seat in piston rod, all that is required is to force back the piston rod and draw it smartly forward, striking the bit against the rock. Blow air through the hose to remove any dirt and

grit that may have accumulated, close the stopcock, pour some oil in the connector, bend and connect the hose to the machine. Oil the rotating gear by removing the screw plug provided in the top cover for that purpose, and the machine is ready to start. Turn air on to the hose from the main, open the stopcock half way, when the machine will start, and *at once commence* cutting the rock, and as the borer penetrates the rock the machine must correspondingly be fed forward by the feed screw. When 4 or 5 in. are bored turn on full air, pour water freely into the hole, and advance the drill by the feed screw according to the rate of penetration. When the short drill has cut as deep as it will reach, stop the machine, screw it back by the feed screw, remove the borer, and replace it by the next longer length; *strike the first few blows at half pressure, to bring the bottom of the hole to the shape of the drill*, then full speed until the bit has bored as far as it will reach, when again replace it by a longer length, and so on until the required depth is attained.

In running *a new rock drill with steam*, it may sometimes happen that the machine will not start readily, or, after a few minutes, work at a low speed; this is caused by the unequal heating of the cylinder, and will disappear as soon as the machine becomes uniformly heated.

When starting a machine that has been laid aside, and also a new one, pour half a cupful of paraffin into it to remove the gum of the old oil, and after a few minutes' run, oil with good suitable oil.

Keep your machine properly oiled, take care of it and use it properly, and you will find it the miner's most useful tool, and one that will last for years with very trifling repairs.

The introduction of rock drills into mines is not always accomplished without some difficulty and resistance from the miners themselves, who fancy that they will be thrown out of employment when the machines are set to work. I met with an experience of this kind when installing a drilling outfit in a mine in the South of France. The miners were so much against the introduction of machine work, that the drills were set to work under police protection, but notwithstanding all our precautions the first man who undertook to run one was assassinated, and the roof of the underground manager's house was destroyed by dynamite.

ROCK DRILLING MACHINERY.

ESTIMATION OF A COMPLETE PLANT OF MINING MACHINERY FOR DRILLING SIX OF SIZE "D" (3-IN. CYLINDER) ROCK DRILLS OF INGERSOLL-SERGEANT TYPE BY COMPRESSED AIR.

<i>, etc.</i>	\$	\$	Shipping Weight.
Standard mining drills, size "D" (3-in. cylinder), complete with valves and wrenches (unmounted), 5 each	1,650		
Style double screw tunnel columns, complete with arms and clamps, \$60 each	360		
Price of shaft bars, \$50 each; tripods with lights, \$50 each)			
Set of fitted drill steels for drilling holes up to 100 ft. in depth, \$16 per set	96		
50 ft. each) 1-in. rock drill air hose with couplings attached, \$29 per length	174		
Set of blacksmith's tools for sharpening drill bits	10		
Total for drill outfit	2,290	4,287 lb.	

Compressor, etc.

Standard class "A" straight line air com- pressors, of piston inlet cold air pattern, size "O," cylinder 16 in. diameter, stroke 18 in. complete as specified, provided with improved air circulating jacketed cylinder and heads, automatic and adjustable regulator with unload- ing device for air and steam. Capacity of compressor sufficient to run seven of size "D" (3-in. cylinder) rock drills	2,500		
Air receiver, diameter 42 in., length 120 in.; painted complete with gauges, safety valve, fittings	222		
70 horse-power horizontal tubular boiler of standard front pattern, complete with stack, grates, rollers, brackets, and all fittings, in- cluding injector, complete, ready to fire, except piping work	1,344		
Price of a portable boiler, 70 horse-power, complete, with injector, ready to fire, \$1305.) motive water front on skids.			
Estimated cost of pipes, valves, and fittings to connect compressor with air compressor and air compressor receiver	95		
Total for compressor outfit	1,161	28,800 lb.	

Cost of complete plant **6,451**

4 in. air pipe for conveying air from the compressor to mine (price subject to market change), at 35 cents per foot	175		
Estimated fittings for pipe line, about	75	250	5,500 lb.

Total say £1340 = **6,701 38,587 lb.**

Men can be furnished to superintend the erection of this machinery,
and instruct others in its operation.
Material delivered f. o. b. cars or boat in New York.

CHAPTER IX.

BORING MACHINERY.

Hand Boring by Percussion—The Surface Arrangements—Tools—Rate of Boring—Cost—Cost of Tools—Hand-power Diamond Prospecting Drill—Capabilities and Cost—The Diamond Drill—Description—Surface Arrangements—Details—Rate of Boring—Cost of Boring—Specification of Drill, and Accessories and Cost.

HAND BORING MACHINERY.—The geologist by his scientific theories cannot always persuade a body of men to risk their capital in the sinking of shafts, in order to prove the existence of mineral wealth under a property. They often, and rightly, prefer to have some tangible evidence, and this can only be obtained by boring either by means of percussion acting through rods with a chisel point or by the rotation of a cutting head or crown in which diamonds are set.

The old-fashioned percussion method is now rarely used for prospecting purposes, as though a simple and effective method of making a hole, it has the great inconvenience of pounding up the strata bored through to the state of slime, so that it is impossible to estimate their value with exactness, or to obtain from the sludge brought up any precise information as to the dip thickness of the beds and other matters of importance.

Before proceeding to describe the Diamond drill, which has practically for mining purposes superseded hand-power drilling by means of rigid rods, I will briefly describe the tools used in the older method. The appliances used may be divided into the head gear, which is erected on the surface and provided with a winch for withdrawing the rods. The rods, which are of iron, are 1 in. square, and from 6 to 10 ft. long, with a screw at

one end and a socket at the other ; and, lastly, the cutting and extracting tools, which are fitted as required to the lower end of the rods.

The head gear consists of a simple framework of wood, with a pulley at the top, and is sometimes in oil regions called a derrick. The height of the pulley from the ground should be a multiple of the length of a single rod, and the greater the height the less time and trouble will be required for lifting the rods from the borehole.

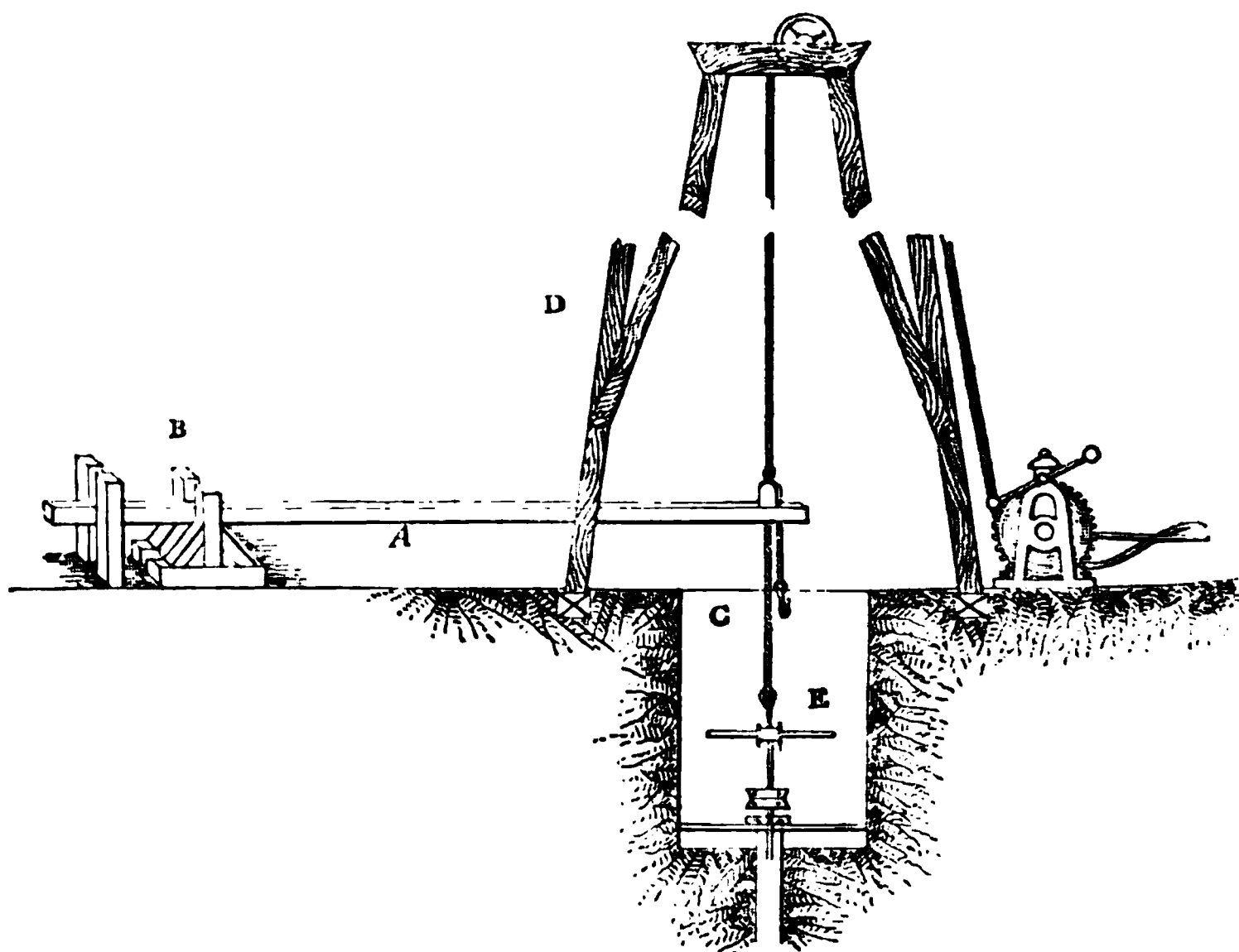


FIG. 126.—HEADGEAR AND GENERAL ARRANGEMENT FOR A BOREHOLE.

In practice it is usually from 45 to 50 ft., and this height is sometimes increased by sinking a small pit, as shown in fig. 126, which represents a simple arrangement suitable for comparatively shallow holes. A is a spring pole which relieves the men of the weight of the rods, and which for depths of over 50 yds., may be conveniently replaced by a lever of Memel fir 10 or 12 ft. long, as shown in fig. 127, the fulcrum being at 18 in. or 2 ft. from the end. The rods are attached to the

spring pole or lever by means of a short length of rope between the hook at the extremity and the brace head E. The brace head is a piece of oak or ash, 3 ft. long and 3 in. diameter in the centre, tapering off to both ends, passing through an eye in a short length of rod, which can be screwed into the socket of the boring rod, and hung from the lever above. A man stands at each end of the brace head, and, aided by the spring pole, lifts the rods, at the same time turning them partly round. The fall of the rods strikes the blow which drives the cutting chisel into the rock. For the first few yards the assistance of the spring pole is not needed, as the men can easily lift the rods if they are working in rock. The drift and gravel which usually overlies the rock at the surface is bored through by means of the shells and augers shown in numbers 1, 3, 6, 7, of fig. 128, and the hole is lined with tubing in order to prevent the sides running in.

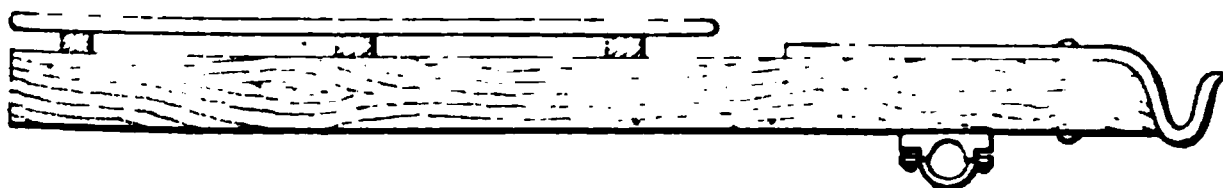


FIG. 127.—LEVER FOR BORING.

When owing to the depth it becomes necessary to use the lever, two or more men are put to press down its extremity, and so raise the rods, while another man at the brace head turns them partly round; the lever is then suddenly let go, and the blow communicated through the rods to the cutting chisel causes it to penetrate into the rock.

The boring tools used are shown in fig. 128.

From time to time, as the depth increases, the rods are withdrawn, and the sand pump or sludger (No. 1, fig. 128) is lowered into the hole in order to remove the rock chippings made by the boring tool. The sludger is an iron cylinder of a slightly less diameter than the bore hole, fitted with a valve at the bottom. It is lowered into the hole at the end of a rope, and is pumped backwards and forwards until full of the *débris*, which cannot escape because of the valve, and is then hauled to the surface.

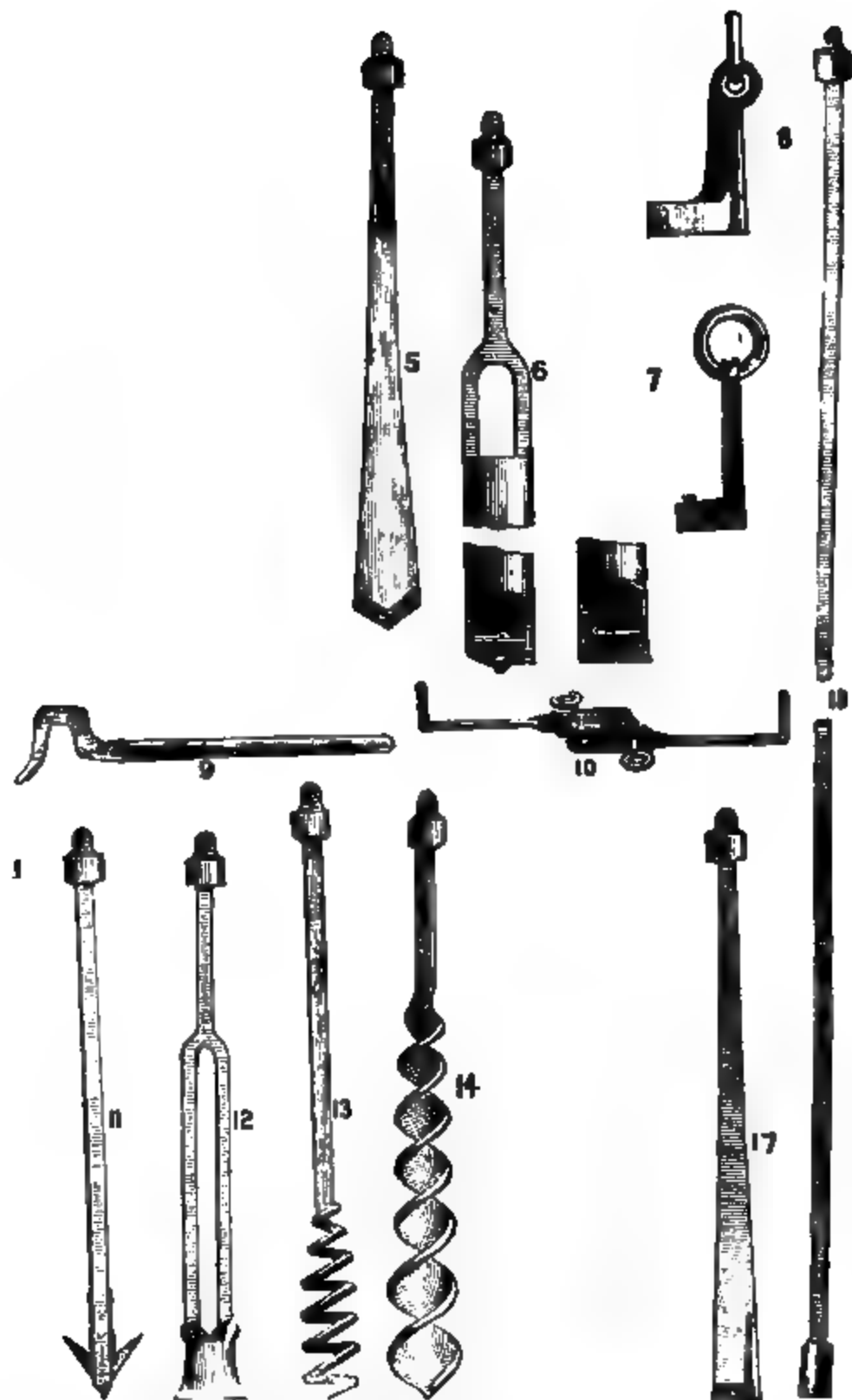


FIG. 128 IMPROVED BORING TOOLS.

List of Boring Tools in Fig. 128.

1. Square shell with valve for bringing up loose
 2. Light-iron screwed well bore pipes. (stuff
 3. er for clay and stiff soil.
 4. V-nose chisels for hard ground,
 5. 8-angler with valve for loose and wet soil.
 6. Shell with valve for loose gravel,
 7. ing dog for raising rods,
 8. of rod-wrenches for screwing and unscrew-

9. Levers for turning rods.
10. Spring dart for drawing pipes in boreholes.
11. Bell-box for bringing up broken bits.
12. Spiral worm for extracting broken rods.
13. Worm auger for loosening stuff in boreholes.
14. Square-nose chisel.
15. 8-nose chisel for hard strata.
16. T-nose chisel for hard strata.
17. Rods with screw joints in 5 and 10-foot lengths.

The contents of the sludge pump indicate roughly the nature of the rock passed through, and the length of the rods gives the depth.

The rate of boring decreases as the depth increases, owing to the time occupied in withdrawing the rods and effecting the necessary changes and clearances. For boring through the comparatively soft sandstone strata above the coal measures, Mr. G. C. Greenwell gives the following scale of charges, the master-borer who contracts for the work finding all the labour and material:—

For the 1st five fathoms, 7s. 6d. per fathom of 6 ft.

For the 2nd five fathoms, 15s. 0d. per fathom of 6 ft.

For the 3rd five fathoms, £1 2s. 6d. per fathom of 6 ft.,

and so on in arithmetical progression, advancing 7s. 6d. per fathom for each additional five fathoms in depth.

The strata met with in metalliferous mining are, however, much harder, and consequently the cost of hand boring will in all probability be double the amounts above given.

The cost of a set of boring tools with 1-in. rods for 100 ft. deep is approximately £45. The rods are 10 ft. long, and cost £1 5s. each, so that a set of tools for depths up to 300 ft. will cost the same as the above *plus* the cost of the additional lengths of rods required.

HAND-POWER PROSPECTING DRILL.—The ordinary form of drill used for making bore holes, as described on page 194, labours under the disadvantages not only of being slow and cumbrous, but also of churning up the rock samples into slimes in the bore hole, so that when they are withdrawn for examination they are in the state of mud, and give only a roughly approximate idea of the nature of the rock passed through. With the Diamond drill, however, a solid core is withdrawn of the actual rock penetrated, and this gives not only the appearance of the strata, with its distinctive markings of the dip and thickness of the bed, but permits of a reliable sample being taken from which the value of the reef or lode may be accurately obtained.

For prospecting purposes the Diamond drill is arranged in the

manner shown in fig. 120. and is suitable for boring holes at any

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1 crown set with diamonds.

6 blank crown bits.

200 ft. of boring rods with couplings.

1 hand pump with hose, etc.

2 core barrels.

2 core breakers.

2 core lifters.

1 crown chuck.

1 set of tools for setting diamonds, and

Complete set of spanners, etc., necessary for erecting and working the machine.

Price of machine complete, with above outfit £170

„ extra crown set with diamonds £25

„ „ boring rods 5/6 per yard.

Weight of machine complete, 12 cwt. Weight of heaviest piece, 150 lb.

The rate of drilling varies greatly according to the hardness of the strata passed through. From 6 ft. to 12 ft. in a shift of 8 hours is the average speed attained.

Down to a depth of 100 ft. two men are sufficient to work the machine, the number of revolutions being from 60 to 70 per minute; beyond that depth, however, three or four men will be required. This hand machine is suitable for boring holes down to, say, 300 ft., and will bore at any desired angle, from the horizontal to the vertical. This permits of its being used for proving lodes or tapping water in old workings, as well as for prospecting. The machine is supplied with an ingenious apparatus for raising the rods, as well as with all the tools necessary for its working, as mentioned above. Instructions are also sent for the resetting of the diamonds on the spot, so that the boring head need not be sent away for this purpose.

If steam-power is available the drill can be driven by a small engine in the place of the men, and a steam pump employed instead of the small hand pump. The portability, which is the great feature of the machine, is, however, destroyed, and if steam is to be used it would be more satisfactory to employ the full-sized drill next described.

The Diamond Drill.—The full-sized Diamond drill (Appleby and Beaumont's patent) is shown in fig. 130, and is capable of putting down holes of 16 in. diameter to depths of more than 2000 ft.,

resembling sand, which have been cut away by the drill in its downward progress.

The power is derived from a 10 horse-power portable engine, transmitted by means of belting and gearing. Over the machine a set of sheer legs are erected as high as possible, with a pulley exactly over the bore hole. By means of a chain connected to the hoisting gear on the drill and passing over this pulley, the boring rods can be lifted out in lengths of three or four at a time, thus saving much time in unscrewing and recoupling the rods. For very deep borings of large diameter a substantial derrick must be erected, as the weight of rods and cores may amount to 10 tons or over. A lean-to shed protects the engine and drill from the inclemency of the weather.

The boring rods are made of solid drawn steel tubes with screwed flush joints, and are caused to rotate by being clipped in a universal chuck to a revolving quill, which has a stroke of 6 ft., and works in the vertical slides attached to the upright side-frames of the machines. The pump is connected to the top of the boring rods by means of a flexible tube. The weight of the rods is counterbalanced so that an even pressure is maintained on the boring crown.

The crown, or boring head, as usually made, is a short length of tube about the diameter of the hole required. Across the edge of it a few grooves are cut, in order to enable the water to pass under it freely as the boring proceeds.

The cutting edge of the crown is formed of nine black diamonds, commonly called carbonates. Three of these are fixed in the outer edge, three on the base, and three on the inside of the crown. Large holes require a greater number. The diamonds set on the outer edge cut the path of the drill in its forward progress, while those on the other two faces enlarge the cavity, and so by abrasion cut an annular groove and leave a solid core in the centre, which fills the inside of the core tube.

The crown is screwed on to the core tube, and this latter for hard rock has a length of about 20 ft. The core tube is of a slightly less exterior diameter than that of the crown, and may be of much greater diameter than that of the boring rods which are screwed into it. The boring rods are hollow, and, when at

BORING MACHINERY.

a constant current of water is being forced down them in to keep the crown cool and clear away the borings, which are carried up to the surface as fine sand.

The rods, and consequently the boring crown, revolve at the rate of about 250 revolutions per minute, and cut their way through the hardest rock at a rate varying from 2 in. to 8 in. per hour.

When a certain depth has been bored, varying according to the strata and the length of the core tube, the core clip is used in attaching the solid portion left standing within the annular hole cut by the crown, and the core is then raised to the surface. These cores are stored for reference, being accurately numbered and kept under lock and key, in order that the information thus gained may be known only to duly authorised persons.

The diamonds used are different to the gems, and are black in colour. They are supplied from certain mines in the district of Minas Geraes, Brazil, and are not found of the same quality in any other diamond fields. They are fitted into holes prepared to receive them in the crown, and the metal is then drawn up around them by means of a punch until only a very small portion of the stone projects beyond the steel ring. Two varieties of diamonds are used—the "bort" and the "carbons." The bort is the real diamond, which, owing to its imperfections, cannot be used as a gem.

It is nearly globular in shape, and is usually set on the outer edge of the crown. The carbon, as mentioned above, is a black stone of varying shape, and is sharp-edged.

The bort is much harder and dearer, the price being about 42s. per carat. The carbons cost about 26s. per carat.

The loss on the crown from the act of drilling half a mile is slight, but the diamonds are apt to get broken from other causes. The average life of a setting, taking accidents into account, may be taken at from six to eight weeks, while the speed of boring varies according to the nature of the work, from, say 8 ft. per day in quartz or granite, to 10 ft. per day of twelve hours in sandstone and slate.

The bore holes may be wholly or partly lined with tubes, in order to prevent the hole from being choked.

As a comparison of the rate of boring by means of rigid rods with that of the diamond drill, it may be stated that a bore hole made by the old method near Berlin took four and a half years for a depth of 4170 feet ; while a diamond bore hole near Lubthein, in Mecklenburg, was put down to a depth of 4000 ft., and completed in six months. The whole of the cores for this distance were obtained, and one was a fine specimen of rock salt over 20 ft. long.

The following is a complete specification of the outfit necessary for a machine, ready for work, for a hole 2000 ft. deep :—

Boring machine, as shown in the illustration (about £395).

Portable engine of 10 horse-power.

2 straps for same.

6 1½-in. flexible hoses.

3 pairs of unions.

2 water unions.

150 ft. of ¾-in. chain.

1 18-in. top sheave, with spindle and bearings.

2000 feet of steel boring rods and joints.

300 feet of 6-in. steel lining tubes, with steel joints.

400 " 5 " " " " "

600 " 4 " " " " "

800 " 3 " " " " "

Special connectors—6 in. to 5 in., 5 in. to 4 in., 4 in. to 3 in.

6-in. to 3-in. steel driving shoes.

2 15-ft. core tubes.

2 special connectors of boring rod to core tubes.

2 " " of rods to 3-in. tubes.

2 6-in. boring crowns

2 5 " " "	} unset.
2 4 " " "	
2 3 " " "	
4 2 " " "	

4 core clips.

2 6-ton hydraulic jacks.

1 3-ton set of blocks and falls.

2 lifting-swivels for rods.

1 set of eccentric clips.

4 patent rod tongs.

2 " tongs for 3-in. tubes.

2 " " " 4 " "

2 " " " 5 " "

2 " " " 6 " "

- 1 complete set of diamond setting tools in lock-up box.
- 1 5-in. parallel vice.
- 1 complete set of spanners.
- 2 patent shifting wrenches.
- 1 1-gallon oil-can and 2 oil-feeders.
- 1 set of stoking tools.
- 1 set of spare valves for the pumps.
- 1 spare set of pinions in steel.
- About 200 carats of carbonates or black diamonds.

This complete machine, engine, and outfit, will cost about £1400 exclusive of the carbonates, which vary considerably in value, and can only be quoted for from week to week. The price is about 42s. per carat.

CHAPTER X.

CONCENTRATION MACHINERY.

Selection of Concentration Process—Coarse Concentration—The Blake Crusher—The Dodge Crusher—The Gates Crusher—The Picking Table and Washing Trommel—Ore Feeders.

As a general rule the ores of metalliferous minerals are not in such a rich state when they come from the mine as to admit of their being at once sent direct to market. They must be enriched by some means or another, so that the worthless gangue, or country rock, may be got rid of, thus increasing the quantity of metallic matter in the ore and avoiding the carriage of useless rock to the melting furnaces, which are frequently at long distances from the mine. The process of enriching the ores is termed concentration, and the successful methods of concentrating ores can be divided into two general systems :—

1. *Coarse concentration*, in which the ore is crushed coarsely, divided into several classes or sizes and treated on various different concentrating machines.

2. *Fine concentration*, in which the ore is crushed finely and treated without classification on one style of concentrating machine.

A combination system is occasionally employed on some ores, in which the material is crushed finely but classified into two or more sizes, being treated on two styles of concentrating machines, or treated separately on machines of one style differently adjusted.

The choice of one or the other of the above systems should depend entirely on the nature of the ore to be treated, though too often the selection is based on chance, prejudice, or personal

limited experience. The ores adapted to coarse concentration are those containing the mineral to be saved in large crystals, masses or seams, so that when broken in comparatively large pieces a good separation is effected between waste rock and valuable mineral. Many ores of lead, zinc, copper, and iron are of this character. The ores adapted to fine concentration, on the contrary, contain the valuable mineral in fine particles or crystals disseminated through the mass of the rock in such manner that a coarse crushing would leave the pieces of waste rock still impregnated with mineral, and a finer crushing therefore essential. Ores of silver, gold, and tin are usually of this character, the silver ores frequently comprising also combinations of lead, copper, and zinc of secondary importance.

The machinery employed for the coarse concentration of ores consists of stone breakers, picking tables, roller crushers, sizing trommels, jiggers, classifying apparatus, fine jiggers, and some form of buddle, table or vanner for the treatment of the slimes. The ore is crushed as little as possible, and every effort is made to avoid the formation of sands and slimes.

For fine concentration, on the other hand, the ore is reduced at once to sand, and then concentrated by means of the same machinery as that employed for the classification and enriching of the sands and slimes made in coarse concentration. In the case of gold and silver ores, the precious metals are, if possible, when in a free state, extracted by means of amalgamation before concentration ; but most of the ores require both the processes. The following general rules as to the selection of a concentration process will be found of considerable utility.

THE SELECTION OF A MILLING OR CONCENTRATION PROCESS.
—The selection of the most profitable process and machinery for the treatment of a given ore is a matter of great importance in a mining enterprise ; but as some ores are susceptible of successful working by more than one process—and in such cases local conditions must determine which method will yield the greatest profit—it is not possible to lay down exact rules covering all cases. The following notes will, however, serve as a guide in some instances, and in all as a general indication of the principles of the processes in common use, and conditions governing their

application. Where there is any doubt working tests should be made.

As before stated, no law can be laid down for the determination of the most profitable process for a given ore ; for where hard cash is in question, theories and practice must give way to exigencies of particular cases. Taking it for granted, however, for purposes of general deduction, that all the above-described processes are equally available, differing only among themselves in simplicity of execution, cost of plant, and consumption of supplies, the following notes will indicate the process to be selected for the ores commonly met with.

If free gold can be panned out and no sulphides = free gold milling.

Free gold found, but also sulphides, which, on being panned out, after free gold is separated, assay sufficiently well to pay for treatment after = free gold milling, with vanning machines for tailings ; chlorination, or smelting for product.

Free gold in small quantities, but much silver present in sulphides = roasting milling ; or free gold milling, vanners and smelting ; or copper plates, vanners and pans.

Chloride of silver ores, and decomposed silver vein outcrops, over 6 ounces per ton = free silver milling.

Silver ores consisting of part chloride or decomposed, and part silver-bearing sulphides = free silver milling, vanners and smelting ; or, if grade of ore is high = roasting milling.

Silver ore with base metal sulphides, if low grade = fine concentration and smelting ; if higher grade = roasting milling.

Low grade silver ores, with grey copper, tellurides, ruby, brittle, or native silver = fine concentration and smelting.

Heavy mineralised ores of lead, copper, zinc, often carrying silver = coarse concentration and smelting.

Lightly mineralised ores of lead, tin, copper, zinc = fine concentration and smelting.

Carbonate or oxide of lead or copper = smelting.

Solid galena ores = smelting, either after simple hand selection, or hand selection and coarse concentration on rejected ore.

Metallic copper ores = stamping with coarse concentration and melting to ingot.

Antimony ores = hand-picking, coarse or fine concentration and smelting for metal.

Zinc-blende and zinc-carbonates = coarse or fine concentration, and reduction by a zinc-smelting process.

Tin ores = fine concentration, roasting, and smelting.

Copper pyrites and copper glance = hand-picking, coarse or fine concentration, partial roasting, and matting; or if on sea-board, shipment of selected and concentrated product to refineries; or if low grade, sometimes lixiviation for copper and silver.

Heavy iron pyrites, carrying gold = chlorination process; or roasting, and intermixture with smelting ores.

To determine if a given low grade silver or gold ore is adapted to fine concentration, the following simple test will suffice:—Take a weighed quantity of average quality passed through a 40-mesh wire screen—not a selected sample, but such as will represent the average bulk of the ore to be treated—say 2 oz. or 4 oz., after having previously assayed the sample. Pan this weighed quantity carefully into a second pan, reserving the mineral concentrated. Pan back again from the second pan into the first, settling well each time, and add the concentrates each time to those first obtained. When no more fine mineral can thus be panned out, dry, weigh, and assay the total concentrations obtained: assay the tailings left. A simple calculation will give the percentage of the assay value of the original ore obtained in the concentrations. The value of the concentrations per ton being determined, and the loss produced in the process, all the necessary details are at hand for deciding if fine concentration will prove profitable. In skilful hands this test is a safe guide for practical work; while in hands not used to panning the results in practice will be better than those obtained in the experiment.

In all cases the sending of a bulk sample of a few tons, if possible, to the makers of the machinery is strongly recommended; and there are some manufacturers who will refuse to supply any machinery unless they have first of all experimented on a small cargo, and can thus confidently guarantee the success of their processes and machines.

In the following pages the process, first of coarse concentration and afterwards of fine, will be taken step by step, describing the

machines which have met with acknowledged success, and the conditions under which they will work to the greatest advantage. Afterwards will be given the description of one or two typical mills showing the arrangement of the machines and the plan adopted to make the whole process as much automatic as possible.

MACHINERY FOR COARSE CONCENTRATION.—*Rock Breakers*.—The first operation of smashing up the rough blocks of ore as they come from the mine is now almost universally done by means of rock breakers of the well-known Blake type, which is illustrated in section in fig. 131. A is the main framing of cast iron; B is a false back, accurately planed and fixed to the frame A,

FIG. 131.—BLAKE-MARSDEN ROCK BREAKER.

against which the jaw plate, c^1 , is accurately bedded either by running in white metal or by the use of soft metal strips, the same mode being adopted in the case of the swinging jaw, c^2 . The jaw plates are reversible, so that, when the lower edge is worn, they can be readily turned round. The jaw plate, c^1 , is held in its position by means of the wedge plate, c^3 .

The swinging jaw, D, is accurately planed, and is rocked on the bearing, E, by means of the plunger, H, acting through the toggle plates, J K. The width between the jaws is regulated by means of the wedge, L; and the swinging jaw, D, is pulled back by the rubber buffer shown below the machine. P is one of two

adherence to the broad fundamental principles on which its construction was based. The stone breaker is driven in the usual way by a pulley, Q, upon a crank, F, instead of an eccentric shaft. Upon this shaft a connecting rod, G, is attached, and at the lower end of the connecting rod is spindled one end of a solid crucible steel lever, the other end of which is fulcrumed to the main frame. As the connecting rod, G, lifts up and down, it actuates the lever, H, in such a manner that the toggles, J and K, give the necessary motion to the swinging jaw, D, for breaking or crushing the material under treatment. One of the great advantages of this machine lies in the fact of there being a false back, B, accurately planed and fixed to the frame, A, itself, against which the three fixed jaw faces, c^1 , c^2 , c^3 , readily bed, thus avoiding any degree of concussion, and also providing a means whereby these faces can be renewed and reversed in position in a few minutes, at any time, without the use of white metal for running up. These faces are fitted with surface strips on the backs, which also facilitate a dead bearing. The swinging jaw, D, is accurately planed, and the wearing faces, c^4 and c^5 , of this are fitted in the same manner as the others. This one advantage can hardly be overestimated, as the full power of the engine is employed in the reduction of the material. The frictional parts in this machine are greatly reduced, especially the main or crank shaft, F, which has been lessened 1 in. in diameter in a medium machine. The adaptation of the parts is such as greatly to relieve the strain upon the machine, and the leverage gained has reduced the power required to drive by about one half. The whole of the shafts and axles are made of best hammered steel. The bearings are pillowed throughout with brass bushes, accurately bored. The toggle cushions are of solid crucible cast steel. The motion obtained by the toggle and lever cushion gives an interrupted movement to the jaw to suit any kind of material; this also prevents clogging. For a certain portion of the revolution of the flywheel, P, the jaw is stationary; the result is a sudden blow by the jaw upon the material, exactly similar to that of a man hitting the stone with a hand hammer. The result, it is claimed, is a much better sample of road metal than it is possible to get by any other machine, and less waste in chippings. These machines

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v

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illustration. The lever is driven by an eccentric on the main shaft, and the jaw shaft rests in movable boxes ; the size of the lower jaw opening being varied by means of packing blocks fixed on either side of the movable shaft boxes, which can be changed by loosening the screws.

For fine crushing, the packing blocks are put in the side nearest the eccentric or driving shaft ; and for coarse crushing they are placed in front next to the screws. The machine, however, is not meant to be a fine crusher in the sense of pulverising. It works best when used for reducing down to the size of nuts, and for this purpose a No. 3 machine, having a jaw opening of 8 in. by 12 in., running at a speed of 220 per minute, is estimated to treat from 2 to 5 tons per hour, according to the nature of the material, and would require from 8 to 12 horse-power to accomplish this. The machine must therefore be considered as for doing the intermediate work between a stone breaker and the stamps or rolls.

The Gates Rock Breaker.—The rock-breaking machines, built on the jaw or Blake principle, have deservedly come into favour with mining men all over the world, both for their simplicity of construction, efficiency, and durability. They have, however, now to compete with a rival machine based upon an entirely new principle, called the Gates rock breaker, for which the makers claim that it will do double or treble the work, will break smaller, absorb one-third less power, and wear better than the jaw machines. A sectional perspective view of this machine is given in fig 134, and a longitudinal section in fig. 135.

The main shaft, G, is of forged steel, is supported on the chilled iron octagon step, P, and held in the centre of the shell, Q, by the top, C. The chilled iron breaking head, F, has two soft iron rings cast into the centre of it, one flush with the top, and the other flush with the bottom. These rings are of sufficient width to leave a space between them the same length as the taper-planed octagon on the shaft, and the space between the rings is cored out octagon a little larger than the taper-planed octagon on the shaft. The shaft, above and below the octagon, is turned on a taper the same length as the width of the soft iron rings in the head, and these tapers, as also that of the planed octagon, all

CONCENTRATION MACHINERY.

towards the top of the shaft. The rings in the head are laid out, the upper one to fit the taper on the shaft above the section, and the lower one the taper below it. The head is put over the top of the shaft, and when it has been driven down between the bearings the octagon faces on the shaft, and in the head come opposite each other. The space between them is run up with zinc, which keeps the head from turning on the shaft, and forms a smooth bearing against the octagon of the shaft. The nuts are screwed down, thus securely fastening the head on the shaft; but it can be pulled off when required, since the whole of the shaft inside the head tapers toward the top.

There are twelve chilled iron liners, *E*, placed inside the shell, the space behind and between them being run up with zinc. The zinc can be removed when required by first driving in the key (which has reverse bevels on its edges), by the use of a wrought-iron or steel pin, through the hole in the shell, *Q*, at 2. There are three openings in the top, *C*, through which the material to be broken is thrown in all round the breaking

and *N* represent two small square oil passages cored in the bottom plate 3, which convey the oil down to the space at *V*. The shaft, *G*, can be raised to regulate the size of the opening at the lower end of the chilled iron head, *F*, and liners, *E*, by the nuts, *S*. A gyrating motion is imparted to the shaft, *G*, by the eccentric box, *D*, which is securely attached to the bevel wheel, *L*, forming a long hub to the same. This eccentric box is rabbitted on the inside and outside of the thickest part, as shown by the heavy black lines, and, as all the wear is on this part, it can be readily rebabbitted, should it become necessary through long use or motion or throw. The outside of eccentric box, *D*, is fitted to fit the bore of the bottom plate, 3, in which it revolves. The inside is bored to fit the journal of the shaft, *G*, but is bored eccentrically, enough to crowd the shaft out of the centre just sufficient to produce a fracture or breaking of the material operated upon between the chilled iron head, *F*, and liners. The shaft, *G*, is a loose fit in the eccentric box, *D*, and does not revolve except when there is no material between the break-head and liners, in which case it revolves with the bevel

wheel and eccentric box, owing to the slight friction the eccentric box causes in revolving around the journal of the shaft, but this ceases the moment any material is put between the breaking head and liners, as the resistance of the material overcomes the friction.

It will be seen that the closest point of contact between the breaking head and liners is always at that part of the head which is exactly opposite the thickest part of the eccentric box, D, and that as the eccentric box is revolved around the shaft the point of contact is constantly moving before the eccentric, so that when the eccentric box has made a full revolution around the shaft the point of contact has moved forward to every point around the liners, E. It will also be seen that the material is broken at the point at which the head and liners are in closest contact, and when the head has been moved to the point of contact opposite the material drops down a little, to be broken again when the head has been moved around to that point again, and when broken small enough drops down on to the inclined diaphragm and slides out through the opening in the shell, QQ. There being three openings in the top, C, through which the material is thrown in all around the breaking head, F, it will be seen that every time the eccentric box has made a full revolution the breaking head has acted upon every particle of material in the space between the breaking head and liners, and that there is not a moment it is not breaking the material at some point. The bandwheel, TV, is a loose fit on the shaft, X. The break pin hub, V, is keyed fast to the shaft, X, and has a hole in it through which is passed the break pin, W, into a hole in the hub of the bandwheel. The break pin is held in place by the set-screws in the break pin hub, V, and is of no more than sufficient strength to stand the strain necessary to break the material being acted upon, and should an accident occur (such as a piece of steel getting into the breaking surfaces), the strain would become so great upon the break pin that it would break off, and the bandwheel would revolve on the shaft, X, while the machine would stop until the article had been removed, and a new break pin put in. The loose collars, H and I, are to keep the dust out of the journal, and gyrate with the shaft, G.

CONCENTRATION MACHINERY.

FOLLOWING REFERENCE LETTERS APPLY BOTH TO FIG. 134 AND
FIG. 135.

- cap for keeping dirt out of journal or ball-joint, between quarter boxes
B B.
- e quarter boxes at journal at top of shaft, G.
- top of breaker.
- brass eccentric box, at bottom of shaft, G.
- e chilled iron concaves or liners.
- chilled iron head.
- main shaft forged steel.
- collar fitted close around shaft, G, to keep dust and fine stone out of
lower part of breaker.
- collar fitted close around shaft, G, to keep dirt and dust out of journal at
eccentric, D.
- an oil hole through collar, I, where oil is poured into journal at eccen-
tric, D.
- a collar cast (solid) on hub of bevel wheel, L.
- bevel wheel.
- , bevel pinion.
- oil hole to let oil to bottom of journal at eccentric, D.
- steel point in bottom of shaft, G.
- chilled iron step under bottom of shaft, G.
- the shell.
- jam nut on screw, S.
- screw for raising or lowering shaft, G.
- driving pulley.
- , flywheel.
- break pin hub.
- s break pin.
- , countershaft.
- , pipe through which old oil is drawn off and the journal at eccentric, D.
washed out with hot water.
- screw collar to keep head, F, from working up.
- hole in shell, Q, where key concave is driven in. This concave is not
bevelled on its sides, and it, or one just like it, must be put back in the
same place, as a bevelled concave cannot be driven in after once run in
with zinc.
- , the cast-iron bottom.
- 6—Is wood frame to which breaker is fitted.
- , widest opening where broken stone is being discharged, when head is
breaking on other side.
- Is boiler iron hopper.

FIG. 134.—SECTIONAL VIEW OF GATES ROCK BREAKER

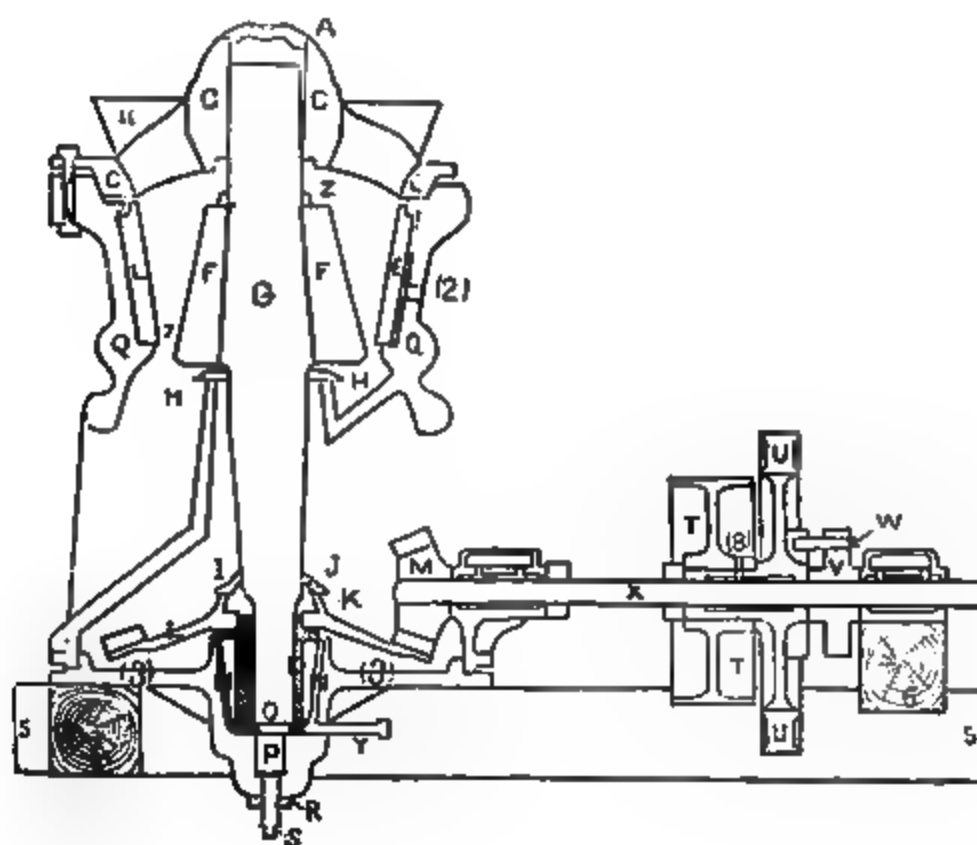


FIG. 135.—SECTION OF GATES ROCK BREAKER.

CONCENTRATION MACHINERY.

The machine is oiled through the hole, J, in the loose collar, 1, finding its way down through the journals to the space, V. An ingenious arrangement of the oil passages, N (of which there are four), in the base plate 3, the motion of the machine

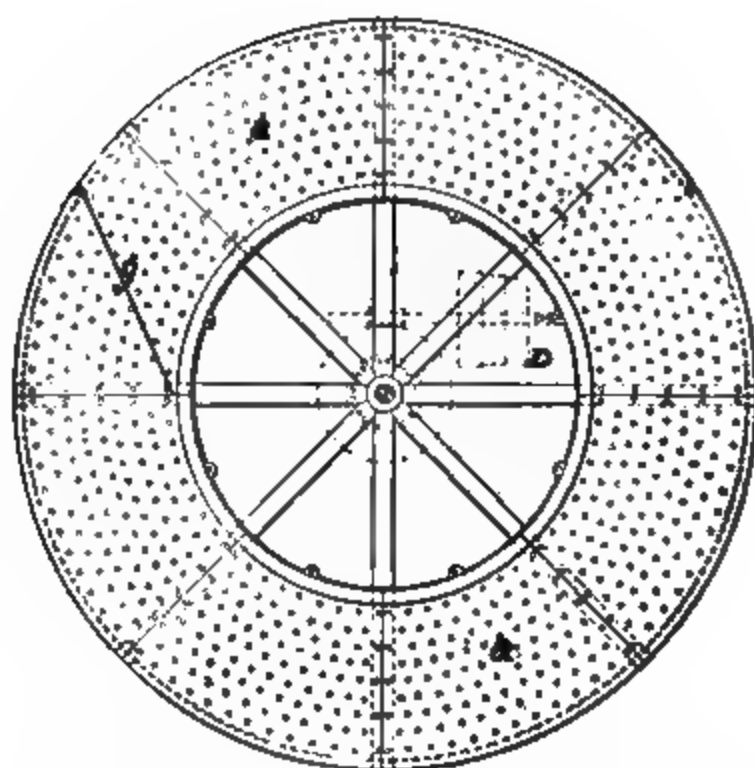


FIG. 136.—ROTATING PICKING TABLE.

is a constant circulation of the oil through the journals of the shaft and eccentric box. The old oil is drawn off through the pipe on the side of the base plate 3, and by pouring hot water through the hole, J, in

the loose collar, 1, the journals are washed out, the dirt and water running out through the pipe.

The breaker is made in a variety of sizes from 00, which is a sampling machine for laboratory work, to No. 8, which weighs 89,000 lb., and is capable of crushing from 100 to 150 tons of rock per hour down to a $2\frac{1}{2}$ in. ring, for which purpose it would absorb from 125 to 150 indicated horse-power.

PICKING TABLE AND WASHING TROMMEL.—After passing through the stone breaker the mineral is roughly classified in a strong washing trommel, the holes in which may be $\frac{1}{2}$ in. diameter or greater, according to the class of mineral; the fine stuff which passes through goes on direct to the roller crushers, but the rougher stuff falls on to a picking table, as in fig. 136.

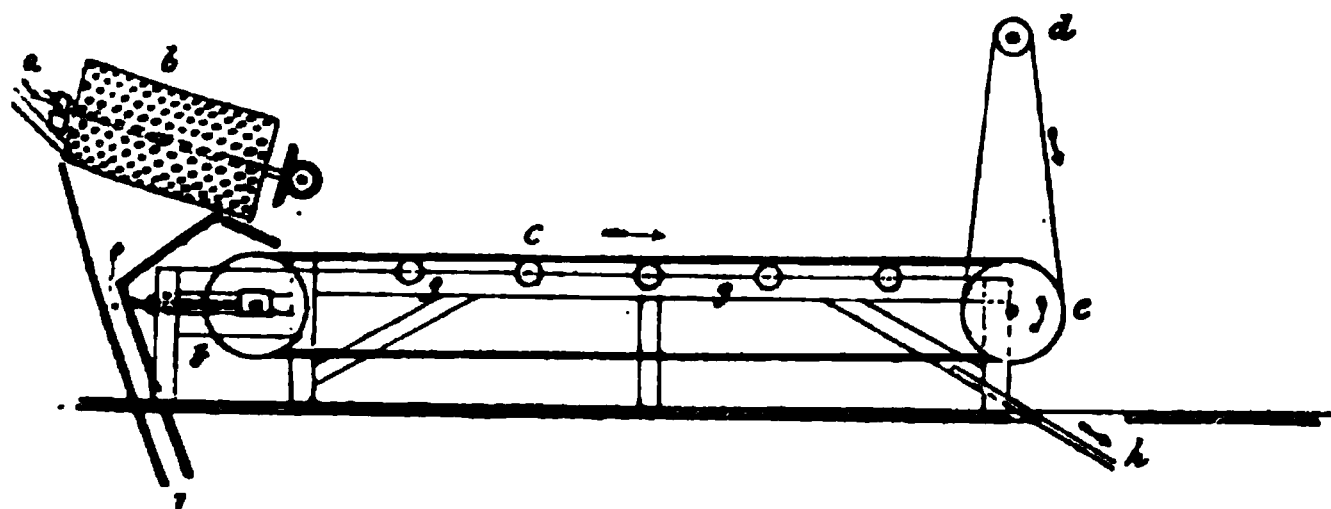


FIG. 137.—BELT PICKING TABLE.

The washing trommel should be of exceptionally strong construction, and is best made of boiler plate, with rolls drilled to suit the ore. It should be well supplied with a strong stream of clean water, sufficient to thoroughly cleanse the ore. In the case of argillaceous ores, which are liable to form into clayey balls, a special washing trommel is used, which is referred to in the description of the new mill at the Neuhof mine, belonging to the Graf Henckel von Donnersmarck Co., near Tarnowitz, in Upper Siberia, on page 445.

Notwithstanding the perfection of modern concentrating machinery, there can be no two opinions as to the value of carefully hand-picking the rich lumps, as well as the sterile pieces of gangue, out of the ore before it is crushed too fine, as not only is this the cheaper method, owing to the saving in metal effected

CONCENTRATION MACHINERY.

h the absence of the losses which always occur after
ing, but also it enables the mill to treat a greater quantity
le ore.

table on which this picking is carried out may either be a
g circular one, as shown in fig. 136, around which stand
omen who are usually employed at this work ; or a long
; hemp belt running on rollers between two lines of
1, as in fig. 137.

n my own experience I am led to prefer this latter, as the
r of women which can be employed at a rotating table is
. by its diameter, which again cannot be very great, owing
structional difficulties ; while in the latter the table can be
of any length, and, as there are two lines of pickers on
ide, they have every opportunity of carefully examining
e as it slowly passes in a constant stream under their

rich ore can either be tipped into shoots, and thus con-
into the magazine, or spalled by hand, in order to enrich
the case of highly argentiferous ore, the picking of even
alls will well repay the cost, owing to the loss of silver
further crushing would involve.

le the women at the head of the table are sorting out the
imps, those at the foot are employed in picking out the
gangue, so that, as far as possible, only ore which cannot
iched without further crushing is allowed to fall over the
nd down an iron-lined shoot, into the hopper of the roller
rs below.

quantity of ore sent on to the mill is thus materially
d, though, of course, there are some classes of mineral in
the ore is so finely disseminated through the gangue that
ole must be crushed down fine, and separated by jiggers,
n slime machinery.

picking table also acts as a rough means of regulating the
of ore to the roller crushers, and also admits of any iron
el scraps, points of broken drills, nuts, and general odds
ids being taken out of the ore, which would otherwise pass
he machinery and cause trouble. At one time I was much
:d by the number of broken drill ends of hard steel which

got into the roller crushers, damaging the face of the rolls, and making a horrible row in the mill. This I put a stop to by ordering the mine blacksmith, who sharpened the drills, to refuse any broken drill without the broken piece, and to report any miner who brought one for repairs.

The miners were then fined for not picking up the broken bits, and finally the number found in the mill was reduced to almost *nil*.

The rotating iron picking table shown in fig. 136 is a circular perforated table of thick sheet iron, A, fixed to a central shaft, C, driven by the gearing, D, which may be placed either at the top end of the shaft, or on floor beneath the table, as shown in the illustration.

The ore is fed on to the table by means of a shoot from the crusher or washing trommel; the water and fine ore drain away through the shield, E, and shoot, F, and the ore left on the table by the women or boys is carried round the table until meeting the fixed scraper, G, it is swept off it into a shoot, which delivers the mineral to the roller crushers.

The disadvantage of this kind of table is that, owing to its small diameter, the number of hands which can be employed in picking is limited. For small mills, however, it is a very convenient machine, and will not only help in saving rich ore, but will also relieve the mill from grinding a useless quantity of waste material.

ORE FEEDERS.—It is important that the ore should be fed regularly to the stamps and roller crushers, or otherwise they will run to but little advantage. In the case of stamps there should always be a thin layer of ore upon the dies, so as to avoid loss of power by unnecessarily pounding the ore in the mortar box. Formerly the feeding of a stamp battery was done by hand, and, in fact, there are some mills in California and Nevada which still continue this. Automatic stamp feeders have, however, been introduced into by far the greater number of mills, and with these appliances it is the stroke of the stamp itself which regulates the speed, as when the dies are deeply covered with ore the stamp does not fall its full height, and consequently imparts but little motion to the tray of the feeder. On the other hand, when there is but little ore on the dies, the stamp falls through its full height

gives a full stroke to the lever of the feeding tray, which accordingly discharges a greater quantity of ore into the feeding

is action will be better understood by reference to fig. 138, is a general view of Tulloch's ore feeder. A is a sheet-iron tray, or feed box, fixed in a suitable framing, O. At the bottom

FIG. 138.—TULLOCH'S ORE FEEDER.

is hopper is a tray, B, suspended on rods, C C. The ore fills the hopper, and would pile up and stick upon the tray or shoot, for the travel and percussive movement which is given to means of the lever, E, and the recoil of the spring, M. The rod is attached to the battery by boring an inch hole through the side block of the stamp stems, so that the end of the rod, J, come under the tappet of the centre stamp, and a motion corresponding to that of the stamp is thus given to the rod, J.

This motion is communicated by means of the lever, I P, and the adjustable rod, H, and so by the upright lever, E, to the tray, B, the sharp recoil of the spring, M, insuring a proper movement to the ore.

For very wet ores a variation of the Tulloch feeder, known as the *Challenge*, is to be preferred. This machine is shown in fig. 139. The circular cast-iron plate shown beneath the hopper, resting at an angle, is rotated by the bevel gear, which in turn

FIG. 139.—CHALLENGE ORE FEEDER.

is moved by an ingenious friction arrangement, varied by the blow received from the tappet on the rod, as in the Tulloch, corresponding to the requirements of the stamp. At each partial rotation of the feed table a small quantity of ore is scraped off by the stationary wings resting on the plate.

Too great importance cannot be attached to the regularity of the feed, whether to stamps or rollers.

With the Cornish rolls used for coarse crushing it is not usual to employ a feeder, as the picking table above acts in that

capacity, but with those used for recrushing a feeder is always attached. The principle is the same as that of the Tulloch, except that the motion is given to the feed tray by means of a cam fixed on a light shaft, driven from an end of one of the fixed roller shafts. This cam, together with the recoil of a spring, gives the necessary travel and shock to the tray, at the rate of two blows for each turn of the roller. The feed may also be assisted by means of a jet of water playing into the tray. The feeders are always supplied with the mill, and are absolutely necessary, as without them the moist ore is sure to jam in the hopper. Special feeders are attached to the improved types of Cornish rolls, with a view to spreading the stream of ore as a thin sheet across the full width of the rolls, and thus insuring an even wear of their surface.

These special feeders are described with the machines to which they are attached.

CHAPTER XI.

COARSE CONCENTRATION MACHINERY (continued).

Roller Crushers—Cornish Rolls—Cost of Crushing—Pulverising—The Krom Rolls—Gates Improved Cornish Rolls—The Huntington Mill—Marsden's Pulveriser—Ball Mills—The Lion Mill—The Gruson Mill.

ROLLER CRUSHERS.—The ore as crushed by the stone breaker is usually of about the size of small macadam, containing an amount of fine smalls, according to its friability. After passing under the scrutiny of the pickers at the sorting table, the next process is to reduce it to a size suitable for jigging, and the machine usually employed for this purpose is that shown in fig. 140.

These roller crushers practically consist of two hard steel cylinders, driven by gearing, and kept in contact by means of strong indiarubber buffers. The ore is fed between the rollers, and must either be crushed by them or force them open. Formerly the rolls were made of iron, and pressed together by means of levers and weights, as may still be frequently seen in Wales. One of the rolls was connected direct on to the shaft of a waterwheel, with or without the intervention of gearing, as shown in fig. 265.

The crushed ore in this mill is classified in the trommel, B, the fine ore passing on to the jiggers, while the coarse is lifted by the elevator, and returned to the rollers. In some small wheels a raff wheel is employed instead of an elevator, but this system is gradually being superseded by the more modern and effective appliances, of which Germany seems to have been the origin.

The modern roller crusher, fig. 140, is driven by means of a belt and gearing. A fast and loose pulley are provided. The fixed pulley has a heavy rim which acts as a flywheel, and helps to

sorting trommels, and be sent on with the coarse tailings to the rollers provided for recrushing, or back to the main rollers if there are no recrushing rolls, and here again they are a source of considerable trouble, which is avoided by careful picking.

The feeding of the large crusher rolls is to a great extent regulated by the picking table above, so that the mineral arrives in one continuous stream, and not in irregular masses. This is an important point, and affects the effective crushing power of the mill, as well as the regularity of its work and freedom from accidents. The other machinery also would suffer from any irregular feeding of the crusher; and as the jiggers give their best results when they are supplied with an even flow of mineral, it follows that the efficiency of their work depends to some extent upon the roller crusher. This remark applies more especially to the coarse jiggers which are fed direct from the trommels below the rollers, and not to those fed from the recrushing mill, the supply of ore to which is automatically regulated by a feeder, such as that shown in fig. 138.

The principal wearing parts of a roller crusher are, of course, the shells. These are made of chilled iron or of steel, of varying diameters and width across the face, according to the capacity of the mill and the practice of the makers, varying from 18 in. to 24 in. diameter for the rough rolls, and 10 in. to 18 in. diameter for the fine crushing rolls, the width of the face being from 8 in. to 12 in.

A stout boss is cast on to the shafts of each the rollers, and this is turned down to a slightly coned shape to fit exactly into the hard shells, which are then secured by bolts and flanges. This is the foreign method; but an almost better practice is to cast the boss of an hexagon shape, about 2 in. smaller than the interior diameter of the shells. The space between the two is then filled up with oak wedges.

A spare pair of shells, ready mounted upon their shafts, should always be kept in stock, so as to replace the ones in use whenever necessary. The operation of changing the rollers occupies a time which depends very much upon the situation of the crusher and the facilities for getting about the work. A set of blocks, chain and crab, as well as a screw or hydraulic jack, should be kept

COARSE CONCENTRATION MACHINERY.

y, and spare rollers as near as possible to the crusher. With everything thus prepared in advance, the operation should not more than ten or twelve hours at the outside.

As soon as the old rollers are taken out the worn shells should be taken off, which is done by burning out the wooden wedges. A new pair of shells should at once be wedged on, and will then be ready, whenever wanted, whether in a few days or months.

The wedging on of the new shells is usually done by the miners. The axle is set up on wooden supports, and the shell

is put on at first loosely by wedges, and the whole turned round until perfectly centred; the wedges are then tightened up with a large hammer, and their ends sawn off, after which small iron wedges are driven in to complete the solidity of the work. The bearings of the crusher sometimes need replacing, and spare bearings should be kept in stock. Usually only the half of the bearing which receives the thrust is of brass, the other half being of cast iron. Care should be taken to prevent the access of dust or grit to the bearings, and the iron protecting caps provided for this purpose should always be kept in their places.

Scrapers are used to remove any accumulation of dirt or mineral from the rollers, and, as these are constantly wearing down, scrapers, made out of scrap iron or old boiler plates, should always be kept handy.

The rollers are sometimes jammed and stopped by an over-charge of mineral, and require clearing, if possible, before the belt is taken off. Sometimes this can be done by means of a bar, but this is a dangerous operation. If a bar is kept for this purpose it should be quite straight and smooth without a handle, so that if it gets caught between the rollers it may be snatched from the rollers, which is not always possible when there is a handle to it. The cost of crushing by means of rolls must depend largely upon the nature of the mineral to be reduced, the hardness of the mineral, cost of material, and of labour, as well as upon the speed at which the rolls are driven. In Germany this latter varies from a circumferential speed of 90 ft. to 180 ft. per minute; while at a mine in France, with which the writer was connected, the rolls were 4 ft. in diameter, revolving at a speed of 20 revolutions per minute, or say a circumferential speed of 160 ft. per minute. If

rolls are worked too fast power is lost, if too slow they are apt to stop if a hard piece gets between them, and in such a case a large proportion of coarse ore will fall through.

The following particulars are given in connection with a Cornish crusher* operating upon steel grained lead ore associated with carbonate of iron, quartz, and hard shales:—Diameter of rolls 21 in.; length of face, 19 in.; weight of new pair, 2700 lb.; weight of worn out shells, 1600 lb.; number of revolutions per minute, 8; speed on face of rolls, 42 ft.; size of stuff before entering, 20 to 60 millimetres; afterwards, 0 to 6 millimetres; weight crushed per hour, $2\frac{1}{2}$ tons; quantity of stuff crushed by a pair of rolls, 2000 tons; time required to take off and put on new rolls, 10 hours; number of hands required at crusher, 3; cost of pair new rolls, £18 3s.; cost of labour and material when changing, £1 7s. 6d.; together, £19 10s. 6d.

Working under the above conditions, the total cost per ton of ore treated would be as follows:—

Redemption of rolls (less allowance for old rolls)	. . .	1½d.
Labour cost	. . . . .	2½d.
Steam-power, 5 horse-power	. . . . .	5d.
Wear and tear of machinery, oil, etc.	. . . . .	1d.
		<hr/>
Cost of crushing 1 ton of stuff	. . . . .	9¼d.

Owing to the feed not being regularly distributed across the whole face of the rolls, they have a tendency to wear in a groove in the centre, and when this takes place they will no longer crush fine. When both coarse and fine rolls are employed, as is always advisable, the same sized shells should be used for each, so that those of the fine rolls, when worn down, can be used for the coarse.

One or other of the shells is very apt to slip in its axle, and this causes the rolls to wear to a cone shape, and finally to jam themselves against the side frames. In order to obviate this it is the practice at some mills to make one shell about 4 in. wider than the other, when it is found that the smaller will wear regularly into the greater, leaving in time a flange on each side.

* "British Mining," by R. Hunt. Crosby Lockwood and Son.

In France the cost of a pair of shells with surfaces chilled to a depth of about 2 in. is approximately £16 per ton.

For the crushing of the tailings from the jiggers, either a smaller set of rolls must be provided or the reserve set of coarse rolls used for this purpose, if special arrangements for the conveyance of the ore to and from the rolls can be made. In some mills, where a set of rolls is devoted to fine crushing only, it is the custom to turn down their faces as soon as they become grooved. For this purpose a slide rest is rigged up across the framework, and the operation conducted as in a lathe; but as the metal of which the shells are constructed is excessively hard, it is a difficult and lengthy piece of work to turn them up true when once they are worn.

In other mills special pulverisers are employed, of which a description will be found on the following page.

To sum up, it may be said that the ordinary Cornish rolls are effective, simple, and cheap machines for crushing rock after the rock breaker, either wet or dry. They are, however, employed where the crushing has not to be carried very far, as in the coarse concentration mills used for lead; though of late years, owing to their being made of an improved form, and driven at a higher rate of speed, they are not without advocates for their use for fine crushing in lieu of dry stamps.

When employed for fine crushing it is essentially necessary that the shells be of good material and kept true on the surface, as well as that the feeding should be regular and across the full width. These are qualities which are claimed by the makers of the Krom rolls, of which a description will be found on page 232. In some cases crushing has been successfully carried out by means of rolls, to pass a screen of from 20 to 30 mesh, but as yet there is not sufficient evidence to show that that crushing with Cornish rolls can be advantageously effected to a finer grade than 30, especially when the ore is of a clayey character.

There is a general tendency in the present type of gold and silver mills to adopt a coarser crushing than formerly, and there is a considerable difference of opinion among mill men as to the need of fine crushing for the roasting of silver ores.

In leaching mills the limit of the coarseness of the crushing is

determined by the results of the roasting, and as rolls produce a less proportion of fine dust than stamps, their use greatly facilitates the subsequent leaching process, and this is an obvious advantage. In amalgamation mills the employment of settlers limits the coarseness of the crushing.

Rolls make less dust or slimes than stamps, and are cheaper in first cost and erection ; but, as the subsequent treatment of an ore determines its method of crushing, no general comparison of stamps and rolls can be made. A comparison is only possible in the special cases where both methods of crushing are applicable.

Pulverising.—The coarse concentration required for the separation of the larger grains of various ores from the gangue which carries them, is followed by a fine concentration in order to affect the separation of the fine grains of mineral in the slimes ; but this fine concentration must have been preceded by a fine crushing or pulverisation of the mineral ; for although a certain amount of dust or slimes is made during the coarse crushing, yet by far the bulk of the ore has to be recrushed, and, of course, when gold or silver ores are under treatment the whole of the ore must as a preliminary be reduced to a fine sand.

The number of machines which have been invented in order to effect this fine reduction is legion, but only a few of them have proved themselves of practical utility, and it is to those few, which will produce certain known results, that the present chapter is devoted, excluding, however, the stamp battery which is described in Chapter XII.

The slow-running Cornish roll (fig. 140) is, when new, a fairly good pulveriser ; but it is useless to expect that the machine, which, after the stone breaker, has to do all the rough work, will also do the fine pulverising ; for, assuming that $\frac{1}{4}$ -in. stuff is fed into a pair of rolls treating 2-in. material, it follows that whenever the shells are opened out by a hard stone, a large quantity of fine stuff will pass through without being touched, and will continue to go round and round in an accumulating quantity. At first, when the shells are new, a certain amount of useful work may be done, but the small average effective result necessitated the treatment of the fine gravel under $\frac{1}{4}$ -in. in a separate pair of rolls. When once this was done, the question arose as to whether the machine could not

be so improved as to compete with stamps when it was applied to reducing to sand mineral which was already crushed down to the size of gravel.

The result has been the perfection of the Cornish rolls up to what are known as the Krom rolls, and also to a pulveriser known as the Gates Improved Cornish rolls, both of which machines,

FIG. 141.—PATENT KROM ROLL, WITH AUTOMATIC FEED AND ALL THE MOST RECENT IMPROVEMENTS.

however, work best on the dry system—that is, when fed with ore not containing more than 5 per cent. moisture; and to the Huntington mill, which is used for wet crushing, and which is, perhaps, the most successful competitor against stamps for certain classes of ore which has yet appeared.

THE KROM ROLLS.—This machine, which is illustrated in fig.

141, and in section in fig. 142, consists of a pair of forged steel shells, A, $2\frac{1}{2}$ in. thick, rolled on to cast-iron bosses, B, running upon the axles, C C.

The shells are 26 in. diameter, by 14 in. wide, and run at a speed of 100 revolutions per minute. The driving axle, C, is in fixed bearings, and carries the driving pulley, G, 7 ft. in diameter.

The second axle is set in a swinging pillow block fixed in two strong cranks, D D, of the end view, fig. 143, which rock upon the shaft, E, set in the cast-iron frame, F. The shaft, M, to which the

FIG. 142.—SECTION OF THE KROM ROLL.

cranks, D D, are keyed, is 11 in. diameter, and set parallel to the roller shafts, so that the loose roller, B, must always move parallel to the fixed one. The one roller is thus firmly fixed in bearings rolled to the bed plate, the other can move parallel to it owing to its being fixed to the cranks of the rocking shaft. The rollers are pressed up close to each other by means of the springs shown in fig. 141, which can be adjusted so as to vary the pressure according to the nature of the ore. Upon the shaft of the loose roller a small pulley of 42 in. diameter is keyed, and this is driven

at the same rate as the main pulley, its only function being to ensure the one roller following the other, which in the ordinary Cornish rolls is attained by means of the deep spurwheels.

The machine is very compact, a pair of 26 in. rolls occupies a ground space of $7 \times 7\frac{1}{2}$ ft. The tyres, which, for a 26-in. roller weigh 816 lb. each, are held in place by two cast-iron heads, B, which are slightly conical in shape. One of them is shrunk on the shaft, the other is slit on one side and slips on to it. Both the heads, B, are so placed on the shaft that the smaller diameter will

FIG. 143.—THE KROM ROLL (END VIEW).

be towards the centre. The steel tyre is turned out on the inside to correspond with this, so that it can be easily slipped over the permanent head and the loose core brought up to it. The two are securely fastened together by the bolts, K, so that when the movable head is drawn up to the permanent one, the slit in it closes up and makes it perfectly tight on the axle. The tyres can, it is said, be worn down to $\frac{1}{2}$ in., and are worn until they are so thin as to become loose from expansion.

The rolls are covered with housing, P, to which an exhaust fan

is attached, for removing the fine light dust, which is carried to a dust chamber.

In order to ensure an even wear of the face of the rolls a special distributor is attached to the feed box which distributes the ore in a thin regular sheet across the whole width of the rolls, and to this even distribution must be attributed the long wear of the shells. At the Bertrand Mill, Cortey, Nevada, two sets of 26-in. rolls are

FIG. 144.—GATES IMPROVED CORNISH ROLL.

stated to have crushed 15,000 tons of ore, at the rate of 150 tons in 24 hours through a 16-in. screen, without renewal. The capacity of the best stamps on the same ore would be about 2 tons per stamp per 24 hours, which makes the rolls equal to a 50-stamp mill, while the wear and tear, as well as the power required, are stated to be one-half that necessary for a stamp mill.

THE GATES IMPROVED CORNISH ROLL.—This machine, like the Krom roll, is an adaptation and improvement of the ordinary Cornish rolls for the purpose of fine crushing, and is shown in the

sectional drawing, fig. 144. The rollers have a diameter of 24 in., and are completely enclosed in a housing. The ore, which should be the size of beans, or say $\frac{1}{4}$ -in. stuff, is fed in at A, upon a vibrating plate, which is so adjusted as to shake off at every blow a fixed quantity of the ore into the trough below, which contains a right and left hand conveyer; this conveyer divides the mineral into two equal parts, carrying each portion in opposite directions, and delivers it into the down spouts which discharge it evenly across the face of the rollers, B, where it is crushed, and falls upon the wire netting of the revolving screen, C.

The crushed mineral which is sufficiently fine passes through the screen into the conveyer trough, E, below, while the coarser particles are carried upwards by the elevating buckets, D, and discharged again between the rollers to be recrushed. The finished mineral is carried along the conveyer trough, E, to the spout, F, whence it passes on to whatever process follows.

The capacity of the machine varies greatly according to the fineness required, and any size of mesh can be used up to No. 50, or 2,500 holes to the square inch, which is the limit of fineness.

Taking hard and dry quartz as a standard, the output of the machine is about as follows:—

No.	mesh	256 holes per square inch,	4 tons per hour.
„ 30	„	900 „	„ 2½ „
„ 40	„	1,600 „	„ 2 „
„ 50	„	2,500 „	„ 1½ „

The weight of a machine with 24-in. rollers is about 8 tons, with the overhead countershaft and pulleys, while the horse-power required to work it to its full capacity is 10 horse-power.

The machine is essentially a dry pulveriser, and the mineral as supplied to it must not be wet or sticky, but so dry as to be readily sieved through a hard sieve; and it must, of course, have been previously reduced down to an even size such as the tailings in a lead mill from the jiggers.

The rollers are fixed at a certain distance apart, according to the results desired, and this adjustment is made before the mill is started, as it cannot afterwards be varied while the machine is

running; or, if preferred, they may be allowed to run together in close contact by the aid of springs or buffers, as is the case in the Cornish rolls.

The great secret of success in both the Krom and the Gates rolls is that the feed shall be spread evenly over the full width of the shells. If this is not possible, then, notwithstanding the hardness of the metal used, the shells will finally wear into grooves, and their efficiency as fine crushers be deteriorated. It is impossible to face up the shells by means of a tool in a slide-rest, owing to their extreme hardness, but an attempt is now being made to perfect a machine with an emery wheel, as a grinding tool, with which it is hoped that the difficulty of turning up the shells when worn will be got over.

THE HUNTINGTON MILL. — The improved forms of roller crushers already mentioned are especially adapted to dry crushing, and do not present any striking departure from the old-fashioned Cornish rolls. In the Huntington mill, however, an entirely new principle is brought into play. The rolls, instead of being fixed on parallel shafts pressed together by buffers, are suspended vertically, and crush by the centrifugal force which is called into play when the frame on which they are hung is set in motion. The mill is now in its seventh year of use as a competitor to stamps, and the following are the advantages which are claimed for it:—

The cost of same capacity is not more than one-half that of stamps.

Freight to mine one-fourth that of stamps.

Cost of erection at mine one-tenth that of stamps.

It runs with one-third the power per ton of ore crushed.

The wear is less than that of stamps.

The wearing parts are easily duplicated.

It has a much better discharge, and leaves the pulp in better condition for concentrating.

It is a better amalgamator, saving fully nine-tenths of the gold in the mill (the balance can be saved on plates in the usual manner).

Its simplicity of construction obviates the need of mechanical skill.

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The discharge of the ore is through the screen fixed for half the circumference of the mill just above the roller path or crushing ring.

An adjustable scraper is fixed in front of each roller, which dashes the mineral and water on to the crushing ring.

The rollers are so slung that a space of 1 in. always remains between them and the bottom of the crushing pan, and into this mercury is put, and inside amalgamation takes place. For the effective working of the mill, the same considerations should be observed as for all other types of crushing machines; the mill should not be expected to do the work of a stone breaker. The ore supplied to it should first of all be reduced to under $\frac{1}{2}$ in., and the feed should be regular. One difference between this mill and the stamps is that the centrifugal motion throws outward against the crushing ring all the heavier portions of the ore, in contradistinction to the lighter and smaller particles of ore which always intervene themselves between the crushing surfaces in a stamp battery. The mercury is not beaten or pounded by the machinery, and thus flowing is minimised. The sulphides are not reduced to an impalpable powder difficult to concentrate to the same extent as in most machines, and consequently are in a better state for concentration.

The capacities of a Huntington mill is estimated as follows, when working upon ordinary gold quartz :—

Diameter of Pan.	Weight.	No. of Revolutions.	Capacity per 24 hours.	H.P. required.
3½ feet	7,000 lb.	90	12 tons	4
5 ,,	11,000 ,,	70	20 ,,	6
6 ,,	20,000 ,,	55	30 ,,	8

The pulp passing through the screens is treated upon amalgamated copper plates placed in front of the mill as in a stamp battery, and can afterwards be concentrated upon fine vanners or by other means.

MARSDEN'S PULVERISER.—The success of the Blake machine as a stone breaker naturally led the inventor to endeavour to adopt the same principle to the fine crushing of ores, the result

the production of the machine shown in fig. 146, which is arranged as to allow nothing to pass away from it until it has been reduced to the degree of fineness controlled by the size of

FIG. 146.—THE MARSDEN FINE ORE PULVERISER.

mesh in the trommel fixed above the crusher. P is one of a pair of heavy flywheels; G is the driving pulley; R is a connecting rod acted upon by the crank shaft, P', and working the lever, C

whose fulcrum is at D, giving a downward and forward motion to the grinding jaw, B.

At the commencement of every revolution till the centre is reached, the connecting rod draws up the end of the lever, which causes the grinding jaw to have a forward and downward motion of immense power upon the material in the mouth between jaw faces, H and G. At the remaining portion of the revolution the exact reverse takes place, and the material operated upon falls into an elevator at the side, which conveys it to a polygonal screen fixed over the machine, covered with gauze according to the fineness of product required. All that is not fine enough passes out at the end of the screen through a small shoot, L, into the mouth of the machine, and is again operated upon with the regular feed.

The machine is adjusted, as in the stone breakers, by means of the wedge, M, and the fineness of its product is regulated by the mesh of the screen. It can be used either for wet or for dry crushing with equal advantage, and from personal experience of it is well adapted for the work of pulverising.

The quantity which they will pulverise per hour necessarily varies with the material under treatment, as does also the power required to drive the mill. The wearing parts are the two jaw plates and the two side plates. These machines are made in five different sizes, and one with jaws of 12 in. \times 3 in. at the mouth will crush 10 cwt. per hour down to 2,500 holes per square inch, for which purpose it would require 5 nominal horse-power. Each machine will do approximately 20 per cent. more through 1,600 holes, 30 per cent. more through 900 holes, and 40 per cent. more through 400; while for crushing finer than 2,500, it will do 25 per cent. less through 4,900.

THE LION[®] MILL. — The Globe Mill Company, of Stratford Market, E., continue to improve upon their centrifugal one-ball mill, which for some years has been before mining men as the most successful ball mill yet invented. Their latest patented improvement is called the "Lion" mill, designed especially for crushing hard mineral ores, for which it is claimed that a mill with a 15-in. ball, wet or dry, will pulverise a greater quantity of ore than a 25-stamp battery, each head and stem of which weighs 900 lb., and strikes at the rate of 90 blows per minute.

The general principle of the Lion is the same as the well-known Globe mill, and consists of a large steel ball, c, fig. 147, whirling around at 100 revolutions per minute in a vertical track, 1

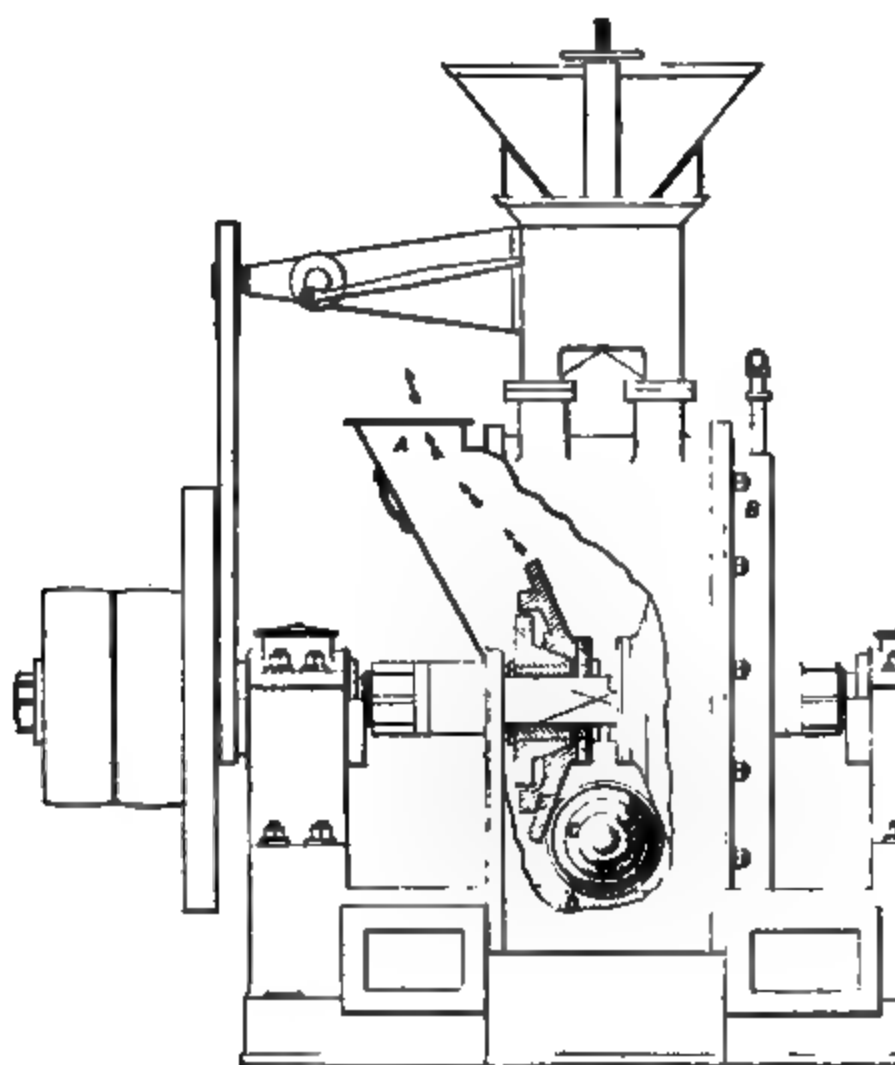


FIG. 147.—THE LION MILL.

by means of two cone plates, E, fixed on a shaft and driven by a pulley at each end, as shown in the accompanying illustration.

After many years' experience, it has been found that the best results are obtained with a ball travelling at the rate of 30 miles per hour; and when it is considered that the ball presents a wearing surface of $4\frac{1}{2}$ sq. ft., and that it can exert a force on the periphery of the track of 40

the centrifugal force due to its mass when revolving at 250 revo-

FIG. 148.—GLOBE MILL AND CLASSIFIER.

lutions per minute, it can easily be believed that at each revolution around a track of 15 ft. circumference it will crush to powder the

8 oz. of mineral, which represents an output of 40 cwt. per hour, or 240 tons per week.

The mill, as arranged for dry crushing, is shown in fig. 148, and is similar to that adopted for the Globe mill. The fine dust is removed from the machine by means of the exhaust fan, and is driven across a series of inverted cones which classify it into four different sizes; and from there it is removed by means of the flexible shoots which convey it into trucks or barrels.

FIG. 149.—GLOBE MILL WITH CLASSIFIER, PULPING ARRANGEMENT, AND ROTATING AMALGAMATOR.

The mill will work either wet or dry. When working dry the pulverised ore is removed, as just explained, by means of an exhaust fan through the opening, A, of fig. 147. For wet crushing water is admitted through the pipe shown, and screens are fitted to the lower half of the side, B, through which the pulp passes to the plates. Another arrangement is shown in fig. 149.

In this the ore from the rock breaker is elevated and falls into the Lion mill, is crushed dry, and then raised by the fan and

deposited into the two inverted wooden cones. From these it is fed into a trough in which a worm is kept revolving. Here it is mixed with water to the proper consistency for pulp, and passes on to the cylindrical rotative amalgamator shown below. Any gold which escapes this amalgamator is caught in the plate which succeeds it, and the slimes or tailings run to waste.

The mill is so arranged that the wear and tear affect the ball principally, and the track in a minor degree; while the result of crushing many thousands of tons proves that the loss of metal in the ball does not exceed 2 oz. for every ton crushed. The Lion mill is manufactured in two sizes; the largest having a track of 15 ft. circumference and 16 in. wide, with a ball 18 in. diameter, calculated to crush 60 cwt. per hour to an 50-in. mesh sieve in fineness. The smaller mill has a track 15 ft. circumference, 12 in. wide, and a ball of 15 in. diameter. It is calculated to crush 40 cwt. per hour down to an 80-in. mesh sieve.

The power required to drive the larger mill is 25 horse-power, and that necessary for the smaller is 16 horse-power, in each case including that absorbed by the rock breaker and accessory machines.

FIG. 150.—SECTION OF THE GRUSON BALL MILL.

GRUSON PATENT BALL MILL.—

Numerous attempts have been made to construct pulverising mills upon the ball principle, and the failures have been almost as numerous.

I will limit myself to describing two ball mills, one of a German and the other of an English make, both of which by the results obtained have some claim to be acknowledged as successful pulverisers of certain classes of ore.

The Gruson mill, manufactured by the Gruson Company, of Magdeburg-Buckau, is shown in figs. 150 and 151.

It consists of a steel drum slowly revolving on a steel shaft. In the inside there are a certain number of hard steel balls of different diameters, which, on the revolution of the drum, continually fall upon and grind the ore which is fed into the mill from the hopper, H, figs. 150 and 151.

FIG. 151.—CROSS SECTION OF THE GRUSON BALL MILL.

It will be seen that the hard steel lining plates, *a a*, are so arranged that the balls fall from one to the other, and that they are each perforated with a number of holes through which the crushed ore falls first on to a perforated plate, *c*, which acts as a protector to the fine circumferential sieve, *d*. The ore which is insufficiently crushed is returned into the mill by the guide plates, *g*, and no ore can leave the mill unless crushed down to the mesh of the outer sieve, *d*. The sides are covered with hard steel

plates, *b b*, and the ore is fed in from the hopper by means of a screw propeller fixed on to the shaft.

The mill will work either dry or wet, and the pulp falls into the hopper, *c*, which forms part of the exterior fixed casing of the mill. In dry crushing, if it is desired to remove the fine dust, the upper funnel, *k*, is connected with an exhaust fan which carries away the light impalpable powder to be deposited on a dust chamber.

All the working parts are made of the best drilled iron and cast steel ; and the makers claim that, owing to their long experience in steel making for armour plates and war material, they have succeeded in turning out a metal which will resist the wear and tear inseparable from a pulverising machine.

CHAPTER XII.

COARSE CONCENTRATION MACHINERY (continued).

Stamps—Specification of 10-Stamp Battery—Hornsby's Battery—Steam Stamps—Imperfections of Stamp Batteries.

STAMPS.—Machines for the purpose of pulverising ore by means of stamps imitating the action of a spalling hammer were in use some three centuries ago in Cornwall, and, indeed, in some of the smaller mines of that county very old-fashioned machines, showing but little improvement in the original make, are still in use. Of these, however, it is not our purpose to speak, and we will at once proceed to the modern stamp batteries, as shown in fig. 152.

It must not, however, be assumed that the Stamp Battery is the most perfect machine of its kind. It is, perhaps, the most perfect, in an all-round way, which has yet been invented.

Amongst its defects are a bad classification of the ore or pulp which consists of all sizes of grains, from an impalpable powder up to the size of the mesh of the screen employed, and the more grave defect caused by the blow of the stamp head flattening the malleable grains of gold, and driving into them hard stony particles which entirely prevent the mercury upon the copper plates from amalgamating with them.

Horse-power.—In order to find the horse-power requisite to drive a given battery, the rule is as follows : multiply the weight of one stamp by the number of stamps in the battery, by the lift in feet, and by the number of lifts per minute, and divide by sixty seconds. Allow one-third of the effective power for friction, then the effective power plus one-third of the effective power as obtained above, is equal to the number of foot-pounds per second,

including the coefficient for friction. The foot-pounds per second divided by 550 give the horse-power required for the battery.

Foundations.—Owing to the rapidity of the blows and the excessive vibration caused in stamping, it is absolutely necessary to secure a firm foundation for the battery, and the usual plan adopted in ordinary ground is as follows :—

FIG. 152.—STAMP BATTERY. TEN STAMPS.

aa Mortar Blocks. *b* Bottom Block. *c* Mud Sills. *dd* Cross Sills. *ee* Mortar Boxes. *ff* Main Posts. *gg* Guides. *h* Screens. *hh* Stamp Stems. *m* Tappets. *nn* Cams. *o* Cam Shaft. *pp* Hangers. *r* Driving Belt. *s* Brace. *t* Stamp Head. *u* Tightening Gear. *v* Shoe. *w* Die. *x* Countershaft.

The vertical mortar blocks, *a*, fig. 152, are generally of a length of from 6 to 10 ft. sunk in a pit dug in the ground, and are well packed for 2 ft. all round with concrete, or clay and stones.

The bottom block, *b*, has a section of 18 in. \times 12 in., and the mortar blocks, *a*, of which there are two or five to each five-head battery according to the size of the timber which can be obtained, are 18 in. thick and of a width equal to the length of the mortar

boxes, *e*, connected together by $1\frac{1}{4}$ -in. bolts, and cross timbers having 12 in. section. The tops of the mortar blocks should be

FIG. 153.—FOUNDATIONS FOR STAMP BATTERY.

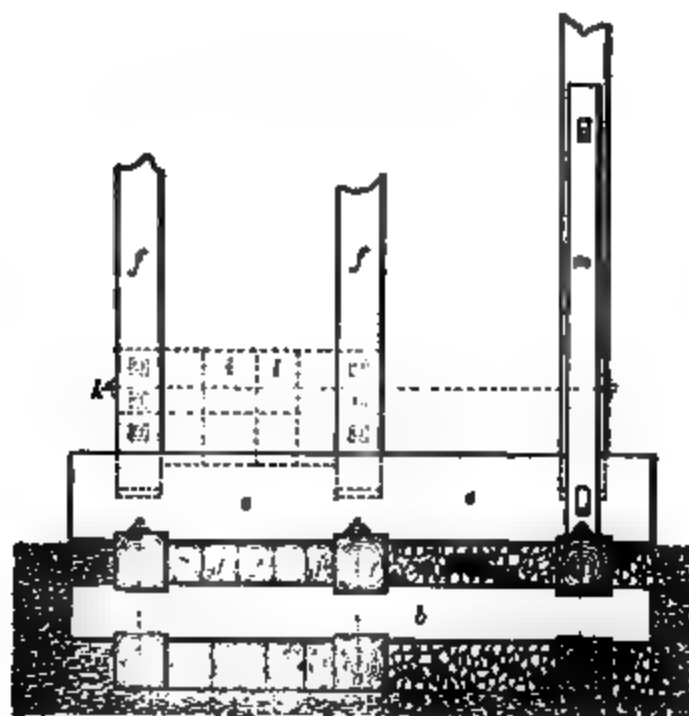


FIG. 154.—FOUNDATIONS FOR STAMP BATTERY.

slightly dished in order to prevent them getting rounded. The cross sills, *d d*, carry the upright main posts, *f f*, and also the

mud sills, *c*, the whole being strongly bolted together. It is well to put a triple layer of well-tarred blanket between the mortar boxes and the blocks, to which they are bolted down with $1\frac{1}{4}$ -in. bolts.

When the ground is marshy or otherwise unreliable horizontal foundations are used which spread over a great area. The ground is dug out for from 1 to 3 ft. deep, carefully levelled, and bottom timbers 1 ft. \times 1 ft. \times 18 ft. are laid parallel to the breadth of the mortar boxes, as shown at *a a a*, fig. 153, one under each upright battery post, *f f*, as shown also in fig. 154. The spaces between these are filled in with shorter blocks of timber about 2 ft. long, arranged side by side under the double cross timbers, *b' b'*, of which there are six, two being close together, *b' b'*, under the mortar block, one near each end, and one halfway between the end and the centre, as *b b*. On the top of this floor of timber are placed other timbers similar to the lower ones, as shown in the section, fig. 153, and the spaces between the timbers, except under the mortar blocks which contain blocks of timber 2 ft. long, are filled up with stones, clay, loam, well rammed in, and the main timbers are well rolled together. The mortar block, *c*, 18 ft. square, is placed on the top of this foundation, and its ends are bound with iron.

If the ground is solid rock, the bottom timbers are arranged parallel to the longer sides of the mortar box, and are let into the rock to which they are anchored by $1\frac{1}{2}$ in. bolts 3 ft. long. The cross timbers are placed over these, and rest on the rock; on these the horizontal mortar block is laid, having short pieces of wood to fill up the space between the centre cross timbers.

The best material to use for these foundation timbers is, of course, oak, but owing to the difficulty of always obtaining this, pine blocks are generally made use of.

Framework.—The framework may be made either of wood, as in fig. 152, or of iron, as in fig. 162. The great advantage of wood is that it combines firmness with elasticity, and can generally be found on the spot. When iron is used it is usually cast, but may be wrought, if for transport in hilly countries. Iron frames last longer than wooden ones, but the constant vibration loosens the bolts, and consequently creates trouble and difficulty.

COARSE CONCENTRATION MACHINERY.

The wooden posts such as those at *f*, in fig. 152, have a cross-section of from 12 in. to 24 in., upwards to 21 in. \times 24 in., and are connected together by the cross beams, *g g*, which also serve as guides to the stamp stems, *k k*. These guides are made of strips of oak, maple, or other hard wood, and in two parts, bored at proper distances apart for the stamp stems, and being set with wedges between, can be closed together as they wear.

The wooden uprights, *f f*, are braced, at least on one side, by struts, *s s*, which enable them to withstand the pull of the belt, *r*. The braces may be of wood or iron, and are generally a combination of both. Iron rods of $1\frac{1}{2}$ in. diameter may be used as struts, and take up less room than wood, and can be easily drawn up; the advantage of wood braces, however, is that they give greater steadiness.

Iron frameworks when used are made of hollow pillars, circular or square in section, or of H-shaped castings. They are fastened to separate timbers to the mortar boxes in order to lessen the vibration.

The two guides, *g g*, already referred to, are placed, the one at a height of about 3 ft. above the mortar boxes, and the other at a height below the top of the stamp stem. They may be made of wood or iron, preferably the former, when their section is about 6 in. \times 6 in. When they are of iron they are lined with hard wood or brass. In their more complicated form they are made in sections capable of adjustment for wear and tear, the best American patents being those of Broughall or Fargo.

Mortar Box.—The mortar boxes, *e*, of fig. 152, were formerly made wholly or in part of wood, but are now generally constructed of cast iron, weighing each about 2,400 lb. For carriage on wheels; but in mountainous districts the mortar boxes can be constructed in sections, which are planed, rebated, and bolted together by strong steel bolts, the top part being of wrought

The usual dimensions of cast-iron boxes, such as are represented in section in figs. 155 and 156, are 4 ft. high, 15 in. broad, and 15 in. long, the bottom being 3 in. thick; but the sides are thinner.

Fig. 156 is a single discharge box, designed for copper lining

plates in the back and front, the former bolted through the mortar and the latter fastened to a block under the screen frame. The die, shoe, head, and part of stamp stem are shown at rest in the mortar.

Fig. 155 is also a single discharge box, but arranged for the copper lining plate, in the front only. It is of similar construction to the other, and is peculiarly adapted for crushing base ores that must be concentrated, and need fine granulation to separate the mineral from the rock. The fineness of the pulp is regulated by that of the screens.

Screens.—The feed hole at the back of the box is about 3 ft. 6 in. long \times 4 in. wide, placed conveniently to the feed platform.

FIG. 155.—MORTAR BOX FOR
FRONT LINING.

FIG. 156.—MORTAR BOX FOR
BACK LINING.

The discharge may be by overflow, or through screens, and may be single or double. The screens are made of finished or slotted sheet iron, copper, or wire gauze. See p. 272, and figs. 168 to 171. Copper is better for fine holes than iron, as they do not fill up with rust. Ordinary iron screens are made of No. 22 D. W. G. sheet. They are numbered and sold according to the size of the ordinary sewing needle that will fit into the holes, from No. 1 to No. 9, or according to the number of holes per lineal inch. The sizes most in use are Nos. 30 and 40, which means 30 or 40 holes to the lineal inch, or 300 to 1600 holes per square inch. Punched screens of Russia iron will last on an average thirty days, but their area of discharge is not so great as with brass wire screens.

The screens are fixed in frames about 3 in. above the top of the dies, either vertically or at an angle, and a piece of canvas is hung over them, against which the pulp splashes as it passes through.



FIG. 157. —
MORTAR
STEM AND
TAPPET.

Each battery of five heads requires two water pipes, the quantity of water varies between 100 and 500 gallons per stamp head per hour, depending upon the nature of the ore treated.

The Stem.—The stem, *k*, of fig. 152, and *a*, of fig. 157, was formerly made of squared wood, but is now constructed of round wrought iron of from 10 ft. to 16 ft. long, and 2½ in. to 3½ in. diameter. The stem is turned up true in the lathe, and both ends are tapered for the last 6 in., so that either may be used as a foot. The stem has either a simple keyway cut on it, or a screw by means of which the tappet is attached.

The Tappet is practically a cylinder of cast iron, weighing about 88 lb., 10 in. long, and 9 in. to 11 in. diameter, as shown in figs. 152 and 157, and having a central bore of the diameter of the stem.

It is slipped on the stem and fastened to it by means of a wrought-iron gib, *b*, keyed up by wedges, *n n*, at right angles to the gib. The projection, *o o*, prevents the slipping of the gib which would cause an uneven wear of the cam face.

Some managers prefer the three-key tappet, but the one with two keys, as in the illustration, is most commonly used. The tappet is double ended, and can be reversed when worn down, and is easily shifted on the stem to any point which may be necessitated by the wear of the cams. Oil is not suitable for lubricating the tappets and cams, as it prevents the revolution of the stamp. It is best to use some tough grease, or a mixture of oil, tar, resin, and tallow, which turns thick on cooling. Stamp hangers, *p*, fig. 152, allow the tappets to rest on them at about 2 in. above the highest point of the cam.

The Head.—The head, *l*, fig. 152 and fig. 158, is of iron, 14 in.



FIG. 158. —
HEAD.

to 20 in. high, and of the same diameter as the shoe, say from 8 in. to 9 in. A head 16 in. high \times 8 in. diameter weighs about 214 lb. In some cases wrought-iron rings are shrunk on the top and bottom $\frac{3}{4}$ in. wide. The head or boss has a socket, *f*, for the neck of the shoe, the taper of both the socket and the neck of the shoe being alike. The stamp stem, *d*, fig. 157, fits into a tapering core on the head, which causes it to bind securely, needing no other fastening, and in order to facilitate the detachment of the shoe, *f*, or the stem, *d*, from the head, two channels, *m m*, *o o*, are left at right angles to each other, through which wedges can be driven in order to force off the stem or shoe when necessary.

The Shoe.—The shoe (figs. 152 and 159) is mostly made of cast steel or the hardest and toughest of white iron. By means of a patent process these shoes can be cast of two kinds of iron at the same operation; the body of the shoe is made of white iron of the very hardest quality, while the neck or stem forming the upper part of the shoe is made of iron possessing almost the tenacity of malleable or wrought iron. This combination of extreme toughness, where the strain is greatest, with exceeding hardness and durability of the parts exposed to wear, makes the patent shoes far more lasting and reliable than those made in the ordinary manner.

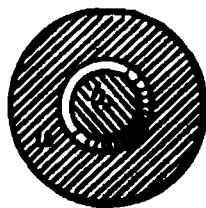
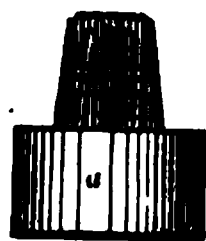


FIG. 159.—
THE SHOE.

The butt is 8 in. to 9 in. long and of a diameter of 8 in. to 11 in. The shank is 6 in. high, half the diameter of the face of the shoe at the base, and $\frac{1}{2}$ in. smaller at the other end. In order to fasten the shoe to the head the shank, *b*, is surrounded with small wooden wedges held in place temporarily by a string; it is then inserted into the shank hole in the head, and afterwards a few blows are given to the top of the stem with a sledge hammer. Afterwards the head is allowed to strike a few times on the die, which is covered with a piece of wood, the battery running slowly. Ordinary round shoes weigh about 157 lb., and should not be worn down less than 1 in. from the shank. An ordinary shoe will crush about 50 tons of quartz before requiring renewal. The space between the shoes is $\frac{3}{4}$ in. The number of drops per

minute may be 90, and the length of the drop 4 in. to 12 in., according to the hardness of the stone.



The order of the drop is 3, 5, 2, 4, 1; 3, 4, 5, 2, 1, 2, 4, 5, 3, 1; or 3, 5, 1, 4, 2.

The Die.—The dies, *w* (figs. 152 and 160), are made of the same material as the shoes, but of slightly larger diameter. Their weight is generally about 95 lb. The foot plate, *a*, of the die is square in shape, with rounded corners. It is $1\frac{1}{2}$ in. thick, and carries a cylindrical piece, *b*, $3\frac{1}{2}$ in. high, of

FIG. 160.—THE DIE.

a slightly larger diameter than the shoe. When worn down to the foot plate it is replaced by a new die, which lasts about twice as long as the shoe.

Cam Shaft.—The cam shaft, *o* (fig. 152), is usually about 5 in. diameter when turned. It is of wrought iron, with two keyways at right angles to each other, and is supported on bearings let into the upright main posts, *f f*. The countershaft, *x*, is seen behind the main posts, and also its driving pulley and belt; and the tightening gear, *u*, by means of which the stamps can be stopped or put in motion without stopping the driving power.

The pulley on the cam shaft is built of wood on cast-iron flanges. This is preferable to the use of a cast-iron pulley, which is apt to crystallise and break, owing to the severe vibration.

The Cam.—The stamps are raised and let fall by means of the cams, *n n*, of fig. 152, which are made of cast or wrought iron, with two arms, as shown in fig. 161.

The face of the cam is from 2 in. to 3 in. wide, and the hub 4 in. to 5 in. The true shape of the cam is a modified involute of a circle, the radius of which is equal to the horizontal distance between the axis of the cam shaft and the centre of the stamp stem. The lift varies from 8 in. to 11 in., and is generally about 10 in. The friction between the cam and the tappet causes the stamp stem to revolve, and thus ensures a more even wearing of the head.



FIG. 161.—THE CAM.

Iron-framed Battery.—The framework of a battery, when of

wood, is usually constructed on the mine, from complete working drawings supplied by the makers of the machinery, except in

FIG. 162.—IRON-FRAMED BATTERY.

those cases where there is no supply of good timber, when the framework must either be purchased with the other parts, or an iron-framed battery employed, such as that illustrated in fig. 162.

The iron frames are so constructed as to be readily transported, but the vibration of the stamps causes the bolts to slacken continually.

The following is a general specification of a 10-stamp battery, such as is illustrated in fig. 152.

- 2 high cast-iron mortars, of latest improved pattern, single (or double) discharge (figs. 155 and 156), planed on bottom, drilled by template, and seats for screen frames planed.
- 2 screen frames of soft pine wood, fitted to mortars.
- 4 wrought-iron keys for same.
- 2 screens of Russia iron or wire cloth.
- 2 sheets of rubber for mortar foundations, $\frac{1}{4}$ in. thick.
- 10 stamp dies.
- 10 „ shoes.
- 10 „ heads or bosses, bored for stems.
- 10 „ stems of refined iron, both ends tapered and fitted to heads.
- 10 „ tappets, each fitted with wrought-iron gib and two steel keys.
- 10 cams, right and left hand, double lift, hubs banded and fitted to shaft with steel keys marked to place.
- 1 cam shaft of hammered wrought iron, turned full length, key-seated and marked where cams are fitted.
- 3 cam shaft boxes, babbitted, bored, and planed on bottom and back.
- 2 „ „ collars of wrought iron, with steel set-screws.
- 1 „ „ pulley, built up complete on double cast-iron sleeve flanges ; and turned true, flanges keyed to cam shaft.
- 1 set upper hard wood guides for stems, bored for stems and bolts.
- 1 set lower „ „ „ „ „ „ „ „
- 2 jack shafts of wrought iron.
- 4 slide boxes or brackets for jack shafts.
- 10 cast-iron sockets for levers.
- 10 hard wood levers for stamp holders.

All bolts, rods, nuts, and washers for the entire framework of battery according to plans.

One set of water pipes, valves and fittings for stamps proper when mill is wet crushing.

The weight of the ironwork, including the wood pulleys and guides for a standard battery of 10 stamps, as above, would be as follows, the weight of the same material for 5 stamps being one-half those given :—

HORNSBY'S ARRANGEMENT OF 10-STAMP BATTERY. 259

10 stamps, each 450 lb.	.	.	.	.	.	16,000 lb.
10 " " 500 "	.	.	.	.	.	18,000 "
10 " " 600 "	.	.	.	.	.	21,500 "
10 " " 700 "	.	.	.	.	.	23,000 "
10 " " 800 "	.	.	.	.	.	28,000 "
10 " " 900 "	.	.	.	.	.	31,000 "
10 " " 950 "	.	.	.	.	.	32,000 "

FIG. 163. - HORNSBY'S 10-STAMP BATTERY

The illustration (fig. 163), which is from a photograph, shows Messrs. Hornsby and Sons', Limited, of Grantham, latest design of stamp battery.

This mill has been specially designed to get the largest amount

of work possible through per stamp, and it is capable of crushing from 4 to 5 tons of hard rock per stamp per day.

The stamps are 950 lb. in weight, and the mortar boxes are of massive construction and great weight, so as to thoroughly withstand the work they have to do. Besides the great thickness of the bottom there is also a steel lining plate of 2 in. thick, on which the dies rest.

The whole of the cams and tappets are made of the very best cast steel.

The shoes and dies are of a special forged steel, having a very long life ; the stamps and shaft are also of forged steel.

The framework, it will be noticed, is very massive throughout, being thoroughly well stayed and bolted together.

Everything throughout this battery is made automatic, so that little or no attention is required by the mill-men.

In front of the battery are the usual amalgamating plates, and these may be followed by blanket strakes, or any of the concentrating appliances mentioned in Chapter XV. on "Fine Concentration," according to the requirements of the ore.

STEAM STAMPS.—Many endeavours have been made to improve upon the stamp battery, which is condemned by some as crude, clumsy, and wasteful ; although for the actual work of crushing with a clear discharge, as in wet crushing, it is perhaps the most effective machine as yet invented. For dry crushing on certain classes of ores it is also the best machine ; but here it is more in competition with various forms of pulverising mills. The great advantages of stamps are as follows :—They are simple to keep in order ; easy to repair by an ordinary blacksmith ; generally understood ; can be run almost constantly ; stopped for repairs a few at a time, and so do not delay the whole mill ; wearing parts are simple castings ; when once erected they will last for years.

In practice they are economical, and when put up it is known that they will do their work without hitch or failure, which cannot be said of some complicated pulverisers.

An important development of the stamp battery is the steam stamp, which works upon the principle of the steam hammer, running at the rate of 90 blows per minute, and capable of crushing

fine a quantity of 150 tons in 24 hours, and coarse 230 tons in the same time.

This class of stamp is illustrated in fig. 164, and is built entirely of iron and steel. The entire framing of the machine consists of

FIG. 164.—THE STEAM STAMP.

four massive cast-iron columns, braced to one another, and securely bolted together, and to the heavy cast-iron rills or bed plates with body-bound bolts. This rigid structure must always remain perfectly in line, and so avoids the excessive wear and tear which a less solid type of construction would entail. The stamp is

COARSE CONCENTRATION MACHINERY.

ated by a vertical steam cylinder, which can be made of any diameter or length of stroke according to the capacity required.

The shaft operating the valves by means of eccentrics and rods, is worked by a pair of machine-cut elliptical steel spurwheels, giving their motion from a countershaft driven from the main shafting by a belt. The object of employing elliptical gear is that the valves may be moved in such a manner as to keep the steam port fully open for admitting the full steam pressure during the down-stroke, and a small opening of the lower port during the up-stroke.

The mortar has four discharge openings, and rests on a heavy cast-iron anvil or bed plate, 20 in. thick, weighing about 11 tons, which is carried by the spring timbers that rest upon the lower columns.

Between the anvil and spring timber is a rubber cushion, 1 in. thick. The angle guide pieces cast on the columns hold the mortar in place. These guides are planed and fitted with jam nuts, adjustable by set-screws and jam nuts. Neither mortar nor anvil are held down by bolts, and the above construction provides necessary vertical elasticity.

The upper and lower guides for the stamp stems consist of cast-iron brackets fitted with removable bronze bushings, which can be easily replaced when worn. The stamp stem is slowly revolved by means of a horizontal pulley on a cast-iron sleeve between the upper and lower guide brackets. This sleeve is brass bushed, and contains two feathers fitting in corresponding slots in stamp stems, by which the latter is rotated.

The piston rod is made of steel, and is connected to the stamp stem by a circular disc, which is encased by a cast-iron bonnet bolted to the flange of the stamp stem. The space between is packed with pure gum rubber packing. This arrangement relieves the shock on piston, and also permits removal of piston for repairs without disturbing the stamp.

Pistons are made of steel, and fitted with bronze packing rings. They are easy of access for packing and repairing when necessary. The water is fed in through the two nozzles, shown on top of mortar, and from the circular chamber is thrown against the stamp stem from every side, preventing it from being cut and worn by the sand. The ore feed, or spout, is placed on top of

the mortar, and is covered over to prevent any pieces of ore from falling outside around the mortar. All bolts and studs including foundation bolts are made of the best Norway iron.

The Anaconda Company has replaced a battery of 120 stamps of 850 lb. each, by thirteen steam stamps, each having a steam cylinder of 15-in. diameter \times 30-in. stroke, for the purpose of reducing copper ores to a coarse mesh, for which purpose eleven are employed, the other two being used for pulverising free melting silver ores.

The shipping weight of a 15-in. \times 30-in. cylinder stamp complete with spring timbers is 140,000 lb., and the 11-in. \times 22-in. stamp is 72,000 lb.

IMPERFECTIONS OF STAMP BATTERIES.—Although the use of stamps is very general, and the machine has justly become popular, it must not be concluded that it is the most perfect appliance for crushing gold quartz; all that can be said is that it holds its own in the front rank of the numerous inventions which have been brought before the public for that purpose. The great desideratum is a machine which will liberate the atoms of gold from their matrix of quartz or other gangue without destroying them, just as the kernel of a nut is freed from its shell by the nut-crackers. As yet no appliance has been invented which will stop short at this point, and the consequence is, that in stamping, the atoms of gold are crushed up and flattened, and by the continued blows beaten out into thin films, into which hard stony particles are driven. The effect of this is that the gold is either so finely divided as to float away with the water, or that the flattened grains are hardened by the repeated blows, and coated with a film of gangue or other impurity, which effectually prevents their being attacked and retained by the mercury of the amalgamated plates. Such is the effect upon the gold, but there is another and very serious imperfection, common to most pulverising machines, and that is that, after crushing the ore down to the requisite size, they keep on pulverising it down to the state of the finest slimes. This is especially noticeable with regard to a stamp battery, as it is necessary to keep the mortar box filled with a sufficient quantity of water to keep the whole of its contents in motion. When the blow of a stamp is struck it creates a small

quantity of fine material, and this, instead of being carried away at once, is drawn back upon the die by the suction caused by rising of the stamp, and so is again pounded when already reduced to a sufficiently fine state. This action continues indefinitely, so that the pulp issuing from the screens contains material in all degrees of fineness, from that of an impalpable powder up to the size of the mesh of the screen. Numerous experiments have proved this, and the following are the results of tests made in Australia upon pulp which had passed from the 7 through a 25-mesh screen.

The size and percentage of the crushings* were as follows:—

Grains $\frac{1}{16}$ inch diameter	12 per cent.
" $\frac{1}{32}$ "	31 "
" $\frac{1}{64}$ "	10 "
" $\frac{1}{128}$ "	47 "

the action of the stamp battery everything tends to show that had the experiments been proceeded with further, much of the material per cent. would have been divisible to diameters of as small as 400 or even 500 to an inch."

The direction in which inventors should seek to improve all crushing machines used for amalgamation purposes is sufficiently indicated from the above experiment. Classification is of the greatest importance in coarse concentration, as will be found explained in Chapter XIII. If anything it is of still greater importance in fine concentration; and the machine which will liberate material without creating valuable slimes is the one which will ultimately take precedence of all others for milling purposes. In roasting and leaching, however, the reverse is the case, as it is an advantage here to have the ore particles very fine, and the more the material is made coarser, so that, seeing that rolls produce a more even and less diversity of size than stamps, it would appear that the form of roller crusher would be the more advantageous for crushing previous to amalgamation, while stamps are preferable where the ore has to be roasted.

Tables showing the quantity of water and the power required for various mills will be found on page 472.

* *Engineering*, August 26th, 1887.

CHAPTER XIII.

SIZING AND CLASSIFICATION TROMMELS.

Sizing, Classification, Grizzlies, Trommels—Rittinger's Scale of Classification
—Screens or Perforated Plates—Hydraulic Classifiers—Spitzkasten.

It may be taken as an established fact that the success of any process of concentration depends upon the exactness with which the grains of mineral have been previously sized and classified, and it is largely owing to the extreme care which is taken in Germany that these two operations are carefully carried out, that the Germans owe their renown as ore dressers.

SIZING.*—Sizing consists of passing grains of ore through a sieve, by which a group of grains is obtained of an approximately equal volume, but of different densities. This is volumetric sizing.

CLASSIFICATION consists of subjecting grains of different densities to the action of a current of water, when a group of grains differing in their volumes, but having equal velocities of fall, are obtained. These grains may be termed equivalents.

The *volumetric* sizing of an ore is effected by means of sieves or trommels, the result being to divide the ore into different groups, having grains of equal volume but of different densities according to their specific gravities, which, when falling through water, will separate from each other, owing to the different speeds at which they will fall. These grains are concentrated in jiggers.

The *classification* of the fine grains of ore is carried out in hydraulic classifiers, pointed boxes, spitzluten, spitzkasten, the result being the production of groups of grains of ore, which will

* "British Mining," Robert Hunt. Crosby Lockwood and Son.

differ from each other in volume and density, but will fall in a current of water with equal velocity, and group themselves at the bottom. The separation of the rich from the poor in such grains having an equal velocity of fall in water is effected by taking advantage of the greater resistance which the grains of large diameter will expose to a washing current of water, as on a buddle or runner, in comparison to the smaller diameter and greater weight of the richer grains of lesser diameter. The former will move with greater rapidity than the latter, and a separation of the two will thus be effected.

The importance of insisting upon a careful sizing of the ores will be evident from a study of the following table.

Table showing the fall of spheres in water in one second of time, all being in millimetres :—

Diameter in Millimetres.	Gold, Sp. Gr. 19·2 Millimetres.	Galena, Sp. Gr. 7·5 Millimetres.	Blende, Sp. Gr. 4·0 Millimetres.	Quartz, Sp. Gr. 2·6 Millimetres.
17·43	2,614	1,570	1,066	780
11·32	2,197	1,320	898	653
8·71	1,849	1,110	750	550
6·16	1,569	935	624	461
4·36	1,307	785	514	385
3·08	1,097	660	448	326
2·17	840	555	378	275
1·54	780	465	317	231
1·08	653	393	266	194
0·77	548	327	210	163
0·54	456	275	188	137

From this table it will be seen that the grains of various metals fall through water at rates of speed varying with their diameters ; thus a grain of gold ·77 mm. diameter will fall through 548 mm. of water in exactly the same time as a grain of quartz of 8·71 mm. diameter, or a grain of galena ·54 mm. diameter will fall through 275 mm. of water in the same time as a grain of quartz of 2·17 mm. diameter. If, however, the grains have been previously sized to equal diameters we have a result which renders their separation possible. Thus a grain of galena of 4·36 mm. diameter will fall through 785 mm. of water in the same time that it takes a similar grain of quartz to fall through half the distance, or 385 mm.

and so with the other minerals. It is evident, however, that the velocity of the fall of the grains depends not only upon their specific gravity, but upon their bulk and gravity combined, and that for a perfect separation of substances according to their gravity it is essential that the particles should be as nearly as practicable of the same size.

It is the above principle which is made use of in jigging, and as it is impossible to have a drop long enough to separate the particles at one blow, we must obtain the requisite drop by repeating the number of the short perpendicular blows. Before, however, we consider the construction of a jigging machine we must, first of all, study the arrangements by which in practice the division of the mineral into sizes is obtained.

The ore as it is blasted down in the mine is of all sizes, from the inconveniently large, which has to be broken up with a sledge hammer, to the fine dust which, if the ore is rich, must be swept up with a broom. To some extent the ore is sorted in the mine, where the sterile gangue is roughly picked out and left to support the roof, or the walls of the worked-out lode. The transport of worthless stuff to the surface being thus avoided, in cases where the ore is sufficiently rich it may be put in bags underground so as to prevent loss. On being brought to the surface the ore may be hand-picked over, previous to being sent to the mill; but the general rule is to send it on direct, and it is tipped over a sloping screen of iron bars called a grizzly, or a perforated iron plate, and here the first operation of sizing may be said to commence.

GRIZZLIES.—The screen or grizzly is made of iron bars from 8 ft. to 9 ft. long, set in a wooden frame fixed at an angle of 45° . The bars may be fixed at from 1 in. to 2 in. apart, according to the class of ore. The coarse stuff is sent on to the stone breaker and then rejoins the fine and passes to the stamps in the case of gold, silver, or tin ores, and some through a sizing trommel having holes of $\frac{1}{2}$ in. to 1 in. in the case of lead, copper, and zinc ores. The coarse from this is fed on to a picking table where the rich is taken out, and then it passes through a roller crusher, after which it rejoins the fine, and the final sizing, before it is sent to the jiggers and concentrating machinery, is effected, in a series of trommels or rotating circular sieves covered with perforated sheet

CLASSIFICATION TROMMELS.

Early flat shaking sieves were employed, but the general practice is now to use circular trommels.

→ 4

TROMMELS.—The usual arrangement of a set of trommels will be seen in fig. 165, each trommel being placed in the same line below the other, the number of trommels depending upon the number of sizes into which the mineral is to be divided. In some cases the trommels are placed side by side, parallel to each other instead of end to end; but in either case each one must be on a different level, so as to allow the ore to pass from one to another. The trommels may be made cylindrical, as in fig. 165, or conical, as in fig. 166, which is a compound trommel having an inside screen of perforated sheet metal and an outside one of wire gauze, thus screening to two sizes at one operation. In the case of cylindrical trommels the shaft must be inclined so as to allow the mineral to progress through without al trommels the shaft may be level. allows for the onward motion of

FIG. 165.—REVOLVING SCREENS FOR WET SIZING.

In the set of trommels shown in fig. 165 the ore from the crusher enters at *a*, and the coarse ore for recrushing travels through the trommel and out at *b*, to be sent back by means of an elevator. Assuming that this trommel has holes of 20 mm. diameter the whole of the mineral passing through there goes on to No. 2 trommel by the shoot, *c*. This trommel has holes of 15 mm., and consequently rejects all ore above that size, which falls down the shoot, *d*, and is fed on to the coarse jigger destined for treating all stuff between 15 and 20 mm.

The ore under 15 mm. passes through the screen, and by the shoot, *e*, to the trommel, No. 3 having holes of 10 mm. In this all ore over 10 mm. is rejected at *f*, and goes to the jigger, which treats ore between 10 and 15 mm. The fine stuff passes through the mesh and on by the shoot, *g*, to another trommel, and so on



FIG. 166.—SERIES TROMMEL.

down to 1 mm. holes, after which the further operation is one of classification by means of water.

Sometimes the space and fall will not allow of the trommels being thus arranged in a cascade, and in such a case the operation, instead of proceeding from coarse to fine, is reversed, and goes from fine to coarse, the whole of the rough ore falling first upon the fine sieves, an arrangement which, if possible, should be rigorously avoided. When these conditions are a necessity, a long continuous trommel, such as the one in fig. 147, is employed. The ore enters at *a* and falls upon a screen, say 2 mm. diameter, through which the fine stuff passes, and is again divided by the outer screen, having holes of 1 mm. The slimes under 1 mm. thus come through *b*. Those between 1 and 2 mm. are rejected at *c*, and the coarse ore inside the main trommel passes first over *d*, when the stuff over 4 mm. is separated, and then over *e*, where

the holes are 6 mm., the remainder is rejected at f , either for re-crushing or to go on to a larger trommel. The grave inconveniences of this form of trommel are, 1st, that the whole of the ore passes over and rapidly destroys the fine screens, and, 2nd, that, owing to the length of the shaft, it is almost certain to bend and sway under the weight of the ore, entailing great wear and tear and a short life for the whole system. In some cases it is impossible to avoid the use of a double trommel, as in fig. 167, but this form, by covering up the inner screen, prevents any small repairs being done to it, which, when left to accumulate, soon involve a serious evil.

In order to prevent the holes from clogging up with mineral, a strong spray of water is allowed to play upon each trommel, and

FIG. 167.—CONICAL TROMMEL.

in some cases wooden beaters are arranged so as to tap the sieve automatically and thus free the holes. The water spray is to be preferred.

The question as to the sizes of the holes in the trommels is one which varies according to the ore to be concentrated, and is best decided by actual experiment at the trial works of the makers of the machinery when the type of machines is also under consideration. As a general rule the mineral to be treated should only be reduced to that size which will allow of the separation of a portion of the ore contained, or of the steriles, if these be in a large proportion, so that when the ore occurs in grains of large size these may be jigged out without having to be crushed down to powder a process which always means loss. The crushing, in short, should be limited to that sufficient to free the grains of ore from the

gangue. The holes in the trommels, therefore, must be based upon this—the largest holes being those which will allow the freed uncrushed grains of ore to pass through them. The rich product being thus separated, the recrushing of the mixed mineral and tailings is again guided by the same principle—viz., that of freeing the grains of ore from the gangue by crushing, but without pulverising them.

As an example of the sizes of the holes in the trommels of a lead mill, we have those in use at the Linares Mill in Spain, of which a description is given on page 442. The holes in descending order are 22·6 mm., 16, 8, 4, 2, 1 mm., below which a classifier is used which feeds four jiggers, and after that a spitzkasten for the finest slimes sent to the Linkenbach tables. On page 445 will also be found the description of the trommels employed at the Neuhoof Mine in Silesia.

Rittinger* adopts 1 millimetre in diameter as the unit of holes for sizing ores for concentration, and the progression beyond this is geometric, as 1, 2, 4, 8, 16 mm., giving for the volumes of the grains, which will pass the holes respectively, 1, 8, 64, 512, 4096 cubic mm. He divides each of these sizes of holes into four classes each with four grades, thus :—

	Diameter in Millimetres	=	In Inches nearly.	
No 1. Rough Stuff	64·0	=	2·51	Coarse.
	45·2	=	1·79	Middling Coarse.
	32·0	=	1·26	„ Fine.
	22·6	=	0·89	Fine.
No. 2. Coarse Stuff	16·0	=	0·64	Coarse.
	11·3	=	0·45	Middling Coarse.
	8·0	=	0·319	„ Fine.
	5·6	=	0·220	Fine.
No. 3. Coarse Sand	4·0	=	0·160	Coarse.
	2·8	=	0·109	Middling Coarse.
	2·0	=	0·078	„ Fine.
	1·4	=	0·055	Fine.
No. 4. Fine Sand and Slime	1·00	=	0·0400	Coarse.
	0·71	=	0·0282	Middling Coarse.
	0·50	=	0·0200	„ Fine.
	0·35	=	0·0137	Fine.

* “British Mining,” by R. Hunt.

There can, however, be no fixed rule for the sizes of the holes, as each separate ore will require an arrangement differing according to the friability of the mineral and its distribution in the gangue.

For fine concentration, as in the case of gold, silver, tin, and

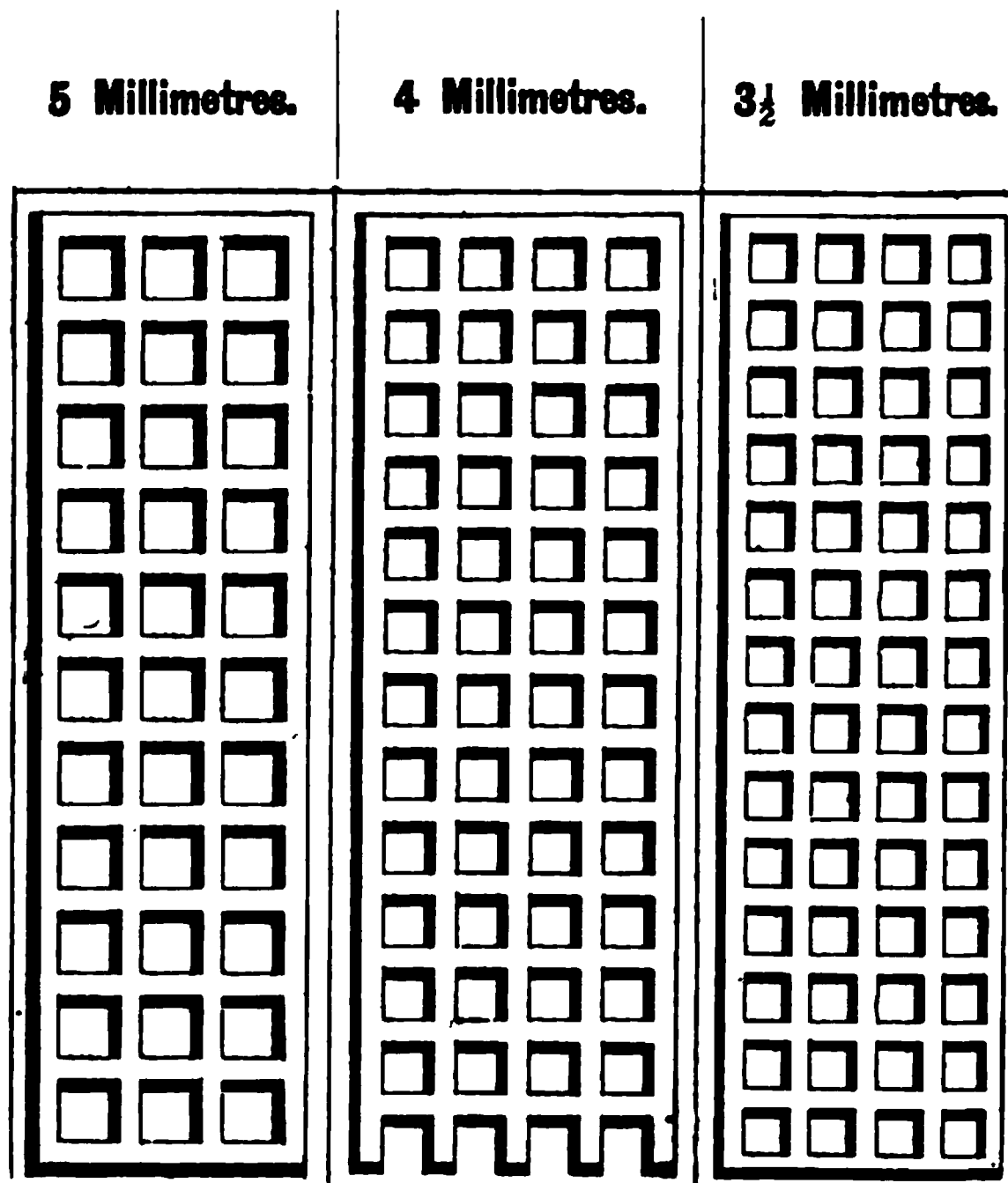


FIG. 168.—SCREENS FOR TROMMELS AND JIGGERS.

sometimes copper ores, no trommels are needed, as the slimes or pulp go direct from the stamps to a hydraulic classifier in the form of a V-shaped box, or spitzkasten, from which the thickened and classified slimes are led either to fine slime jiggers or direct to the vanners or buddles.

SCREENS OR PERFORATED PLATES.—The subject of perforated screening plates is closely associated with that of trommels, and

can advantageously be referred to here before leaving the subject of the "sizing" of ores for that of the classification of sands and slimes previous to concentration.

The material of which the perforated plates is made is Russia

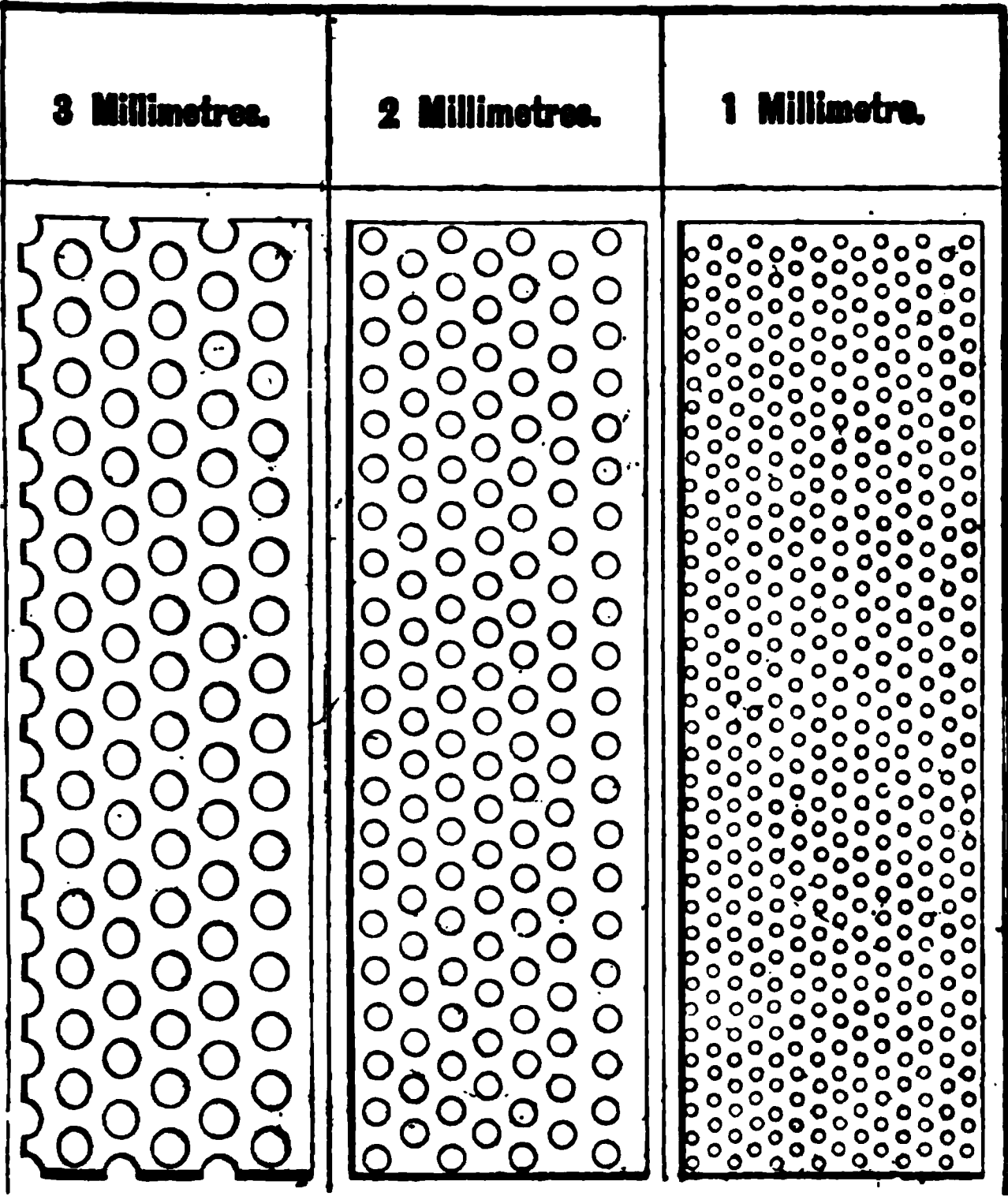


FIG. 169.— SCREENS FOR TROMMELS AND JIGGERS.

sheet iron, charcoal iron, or sheet steel for the larger holes, or sheet copper or wire gauze for the smaller. The plates of the coarse washing trommel, which are subject to rough usage, can well be made of boiler plate with the holes drilled through. Steel wire netting has also been tried for this purpose but my own

experience is in favour of the boiler plate. The mesh of the steel netting soon becomes torn and irregular; for work in a less exposed position it can, however, be used, while gauze of steel wire can also be employed instead of the copper gauze.

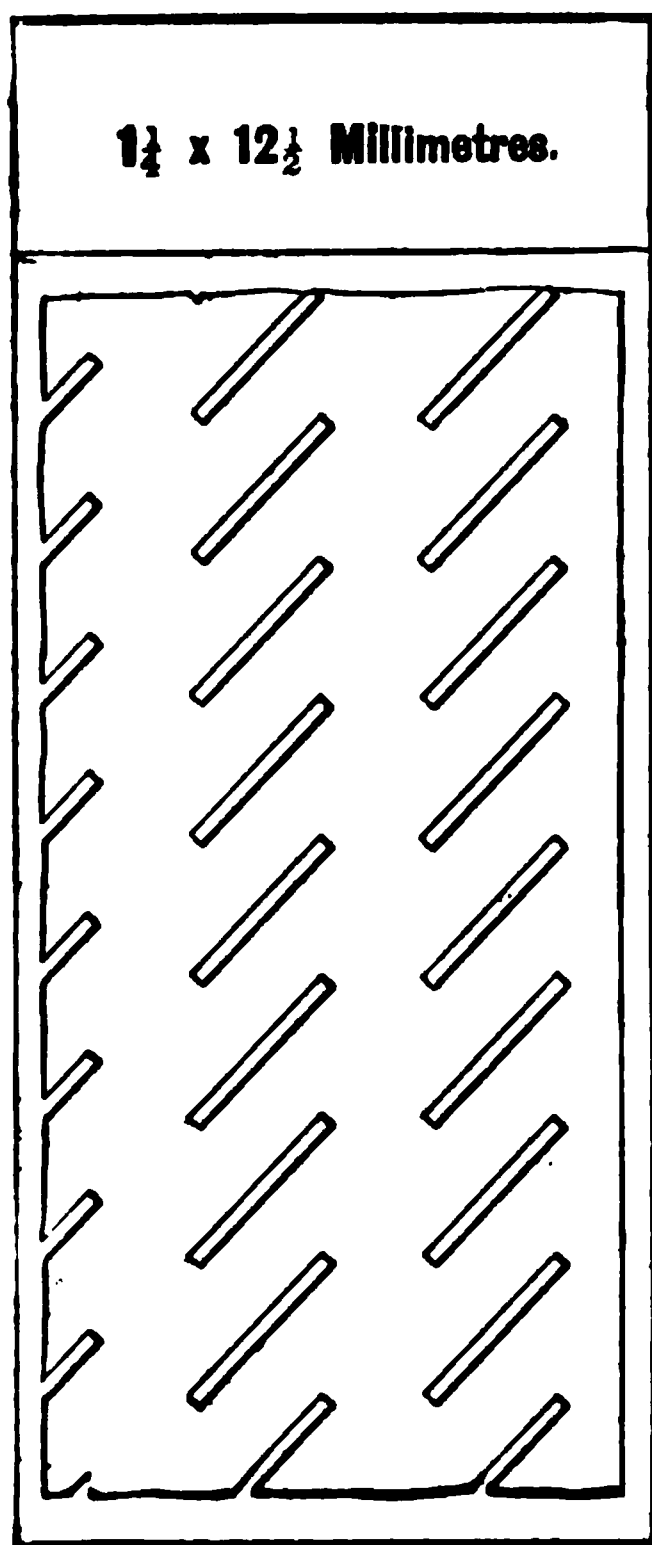


FIG. 170.—SLOTTED SCREEN FOR BATTERIES.

The thickness of the plates varies according to the diameter of the holes. Copper plates are preferable for the finer meshes, as the iron ones are liable to rust up.

The size of the holes may be quoted in millimetres, as is the continental method, or by the number or size of a sewing needle which will fit the hole of the screen, or the width of the slot if slotted plates are preferred.

For battery screens the number of holes per lineal inch is given. The holes in the plates should always be punched, and the roughened side left by punching turned inwards to meet the wear of the pulp or slimes. In stamp batteries it is estimated that each head of five stamps will require thirteen sets of screens per annum, each set consisting of five sheets of 1 to 1½ sq. ft.

For trommels and the beds of jiggers the holes may be round or square, as shown in figs. 168 and 169. The slotted plates used for stamp batteries are shown in fig. 170, and the steel wire and fine brass wire, or copper screens, also used in batteries, are shown in fig. 171.

The greatest thickness of iron or steel which can be punched with round holes, and the weight of the plate per square foot is given in the tabular statement. The price varies with the thickness of the plate, but in most cases this can be less than that given in the table.

TABLE FOR PUNCHING ROUND HOLES IN IRON AND STEEL.

DIAMETER OF HOLE.		THICKNESS WHICH CAN BE PUNCHED.		IRON.
Inches.	Millimetres.	Iron—No. Gauge.	Steel—No. Gauge.	Weight Sq. Ft.
—	$\frac{3}{8}$	26	28	0·8
—	1	24	26	1·0
$\frac{1}{16}$	—	22	24	1·25
$\frac{1}{8}$	$1\frac{1}{2}$	20	22	1·5625
—	2	18	20	1·875
—	$2\frac{1}{2}$	16	18	2·5
—	3	14	16	3·125
$\frac{1}{4}$	—	14	16	3·125
—	$3\frac{1}{2}$	13	15	3·75
$\frac{5}{16}$	—	12	14	4·375
—	4	12	14	4·375
—	5	10	12	5·625
$\frac{7}{16}$	$5\frac{1}{2}$	9	11	6·25
—	6	8	10	6·875
$\frac{1}{2}$	—	6	8	8·125
—	7	6	8	8·125
—	8	4	6	9·375
—	9	4	6	9·375
$\frac{3}{4}$	—	3	5	10·0
—	11	3	5	10·0
$\frac{1}{2}$	$12\frac{7}{8}$	2	4	10·625
1	$25\frac{1}{8}$	1	2	11·25
$1\frac{1}{2}$	$38\frac{1}{8}$	1	2	11·25
2	$50\frac{1}{8}$	1	3	11·25
$2\frac{1}{2}$	63	2	4	10·625
$2\frac{3}{4}$	$69\frac{1}{8}$	2	4	10·625
3	$76\frac{1}{8}$	2	4	10·625

The slots in the battery screens (fig. 170) are usually set diagonally as shown; but screens can be obtained in a great variety of patterns, either in iron, steel, or copper, according to the necessities of the case.

SIZING AND CLASSIFICATION TROMMELS.

TABLE FOR PUNCHING NEEDLE SLOT SCREENS.

Mesh.	Width of Slot.	Russian Gauge. Thickness.	Equivalent Birmingham Gauge.	Decimal of an Inch.	Weight per Square Foot.
12	'058	15	22½	'0269	1'24
14	'049	15	22½	'0269	1'24
16	'042	15	22½	'0269	1'24
18	'035	15	22½	'0269	1'24
20	'029	14	23½	'02425	1'15
25	'027	13	24	'022	1'08
30	'024	12	24½	'021	0'987
35	'022	11	25	'020	0'918
40	'020	10	26	'018	0'827
50	'018	9	27	'016	0'735
55	'0165	8	28	'014	0'666
60	'015	8	28	'014	0'666

CLASSIFICATION.—We have seen how the coarser grains of ore are sized by means of trommels and screws into groups of grains of equal volume, and now have to deal with the finer grains, which cannot be handled in trommels, but must be classified, not according to their volume and density, but according to the rate at which they will fall through a given depth of water as already explained.



FIG. 171.—WIRE CLOTH SCREENS.

A hydraulic classifier for carrying out this principle, is shown in Figs. 172 to 175, which are reduced from actual drawings of an apparatus which I once constructed, and successfully used, of this kind, the original drawings being supplied by the works of German machinists who supplied the machinery. The classifier supplied the mineral to two five-compartment percussive lever jiggers. The slimes which arrived at the smaller or

inlet end, shown by the arrow on the plan (fig. 172), spread themselves out with gradually decreasing velocity, the heavier and larger particles falling first, the lighter and finer being carried on until only the finest slimes escaped at the exit and went to the spitzkasten, where they were thickened previous to treatment on the Linkenbach tables.

The classifier is built of either wood or sheet iron. Fig. 174 is a section at the upper and smaller end, and fig. 175 is the section at the further and larger end. A is a smooth inner casing

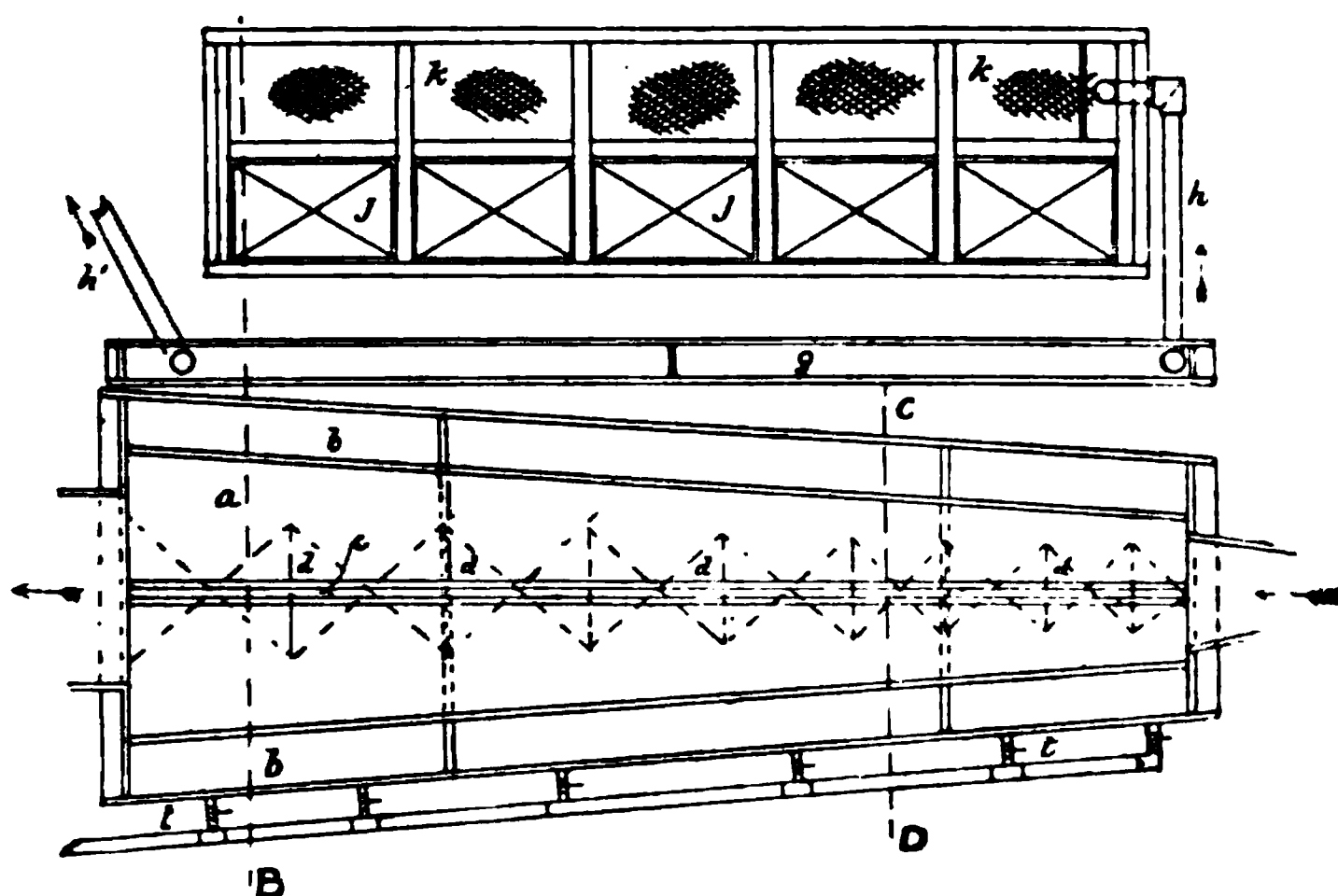


FIG. 172.—PLAN OF HYDRAULIC CLASSIFIER. SCALE 15 MM.=1 METRE.

gradually expanding and deepening, and having a slot, *c*, at its apex about $\frac{1}{4}$ in. deep running the whole length. B is the outer casing, divided longitudinally under the inner casing, *a*, by angular divisions, *d*, from the points of which the pipes, *e*, convey the classified mineral to the trough, *g*, on the outside of the classifier, and at a distance of 500 mm., or, say 19 in., below the surface of the water inside. Fresh water is conveyed into the classifier by means of the tap, *f*, and this, by keeping the level of the water higher in the outer casing, *b*, causes a constant upward stream of water to flow through the slot, *c*, checking the tendency

of the mineral particles to deposit themselves, and separating them into regular groups. The plans are drawn to scale, so that where the dimensions are not given they may readily be obtained.

The classifier is elevated upon a brick foundation, *R*, which is divided into small reservoirs or cases, which received the slimes which fall from the pipes, *e*, when they are opened for cleansing purposes.

The jiggers which treat the classified mineral may either be quite near, as shown in figs. 174 and 175, or at any convenient

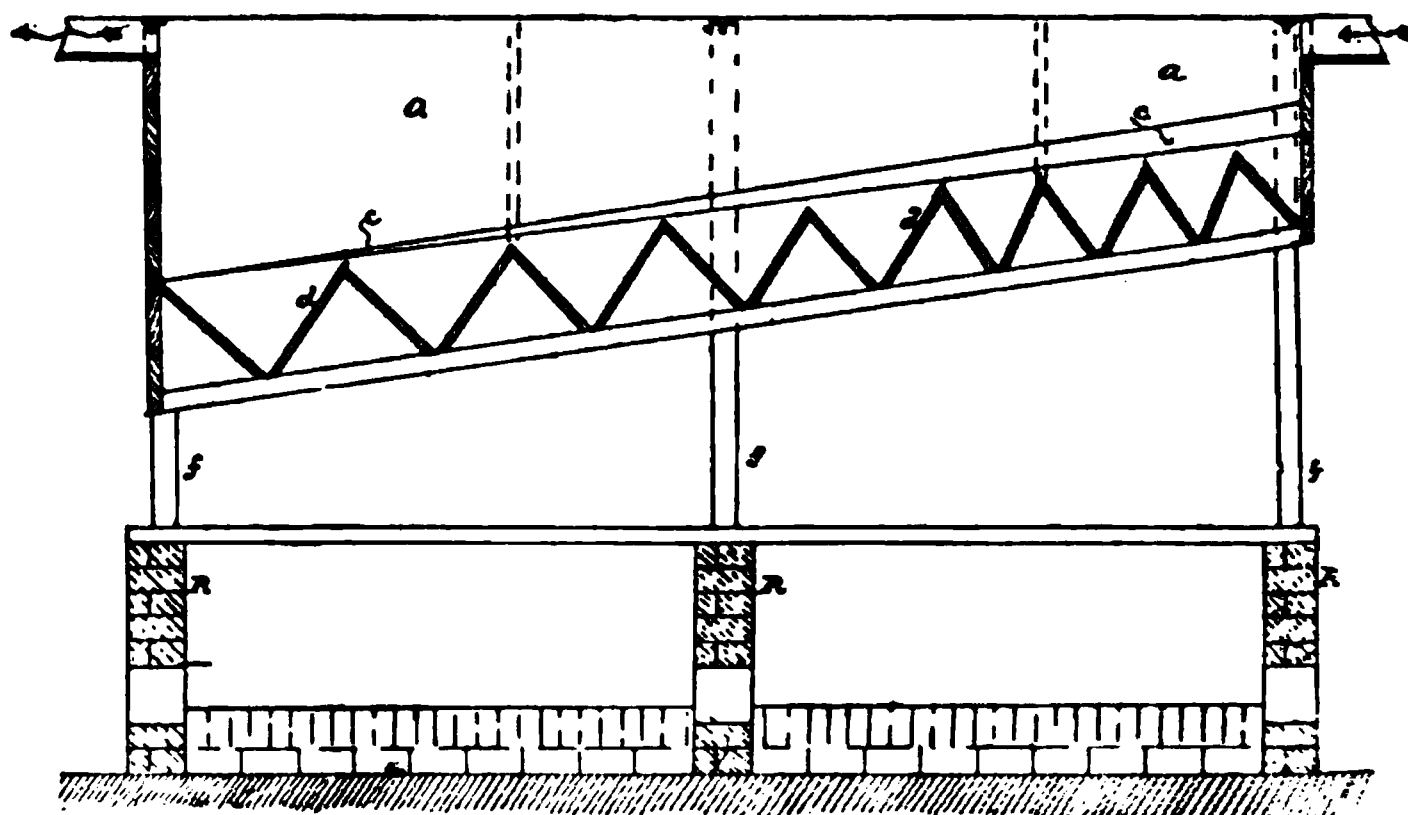


FIG. 173.—LONGITUDINAL SECTION OF HYDRAULIC CLASSIFIER.

distance, provided that there is fall enough to convey the rich thick slime through the pipe, *h'*.

In the cross-section, fig. 174, *i* is the jigger, fixed on a concrete bed, in which the receiving case, *o*, is formed for the reception of the enriched products. The excess water flows away by the channel, *p*. The disc, *l*, is fixed on the driving shaft, and carries a crank pin, whose stroke may be varied according to its position in the slot on the face of the disc.

A short connecting rod is placed between the crank pin and the lever, *m*, which causes the pulsation of the piston shaft, and through it and the piston rod operates the piston, *j*.

The effect of this system of levers is that the down-stroke of the piston is rapid, and the up-stroke slow.

As an appliance for classifying the fine sands, the hydraulic classifier is most efficient, and requires but little attendance beyond the care necessary to prevent the pipes becoming choked with sand. It will be noticed that wooden plugs are inserted at all the angles, and these admit of the pipes being cleared by means of iron rods. The supply of fresh water must be so regulated as to be sufficient to drive off the light slimes, but not so strong as to carry away the coarser sands. There are many forms of

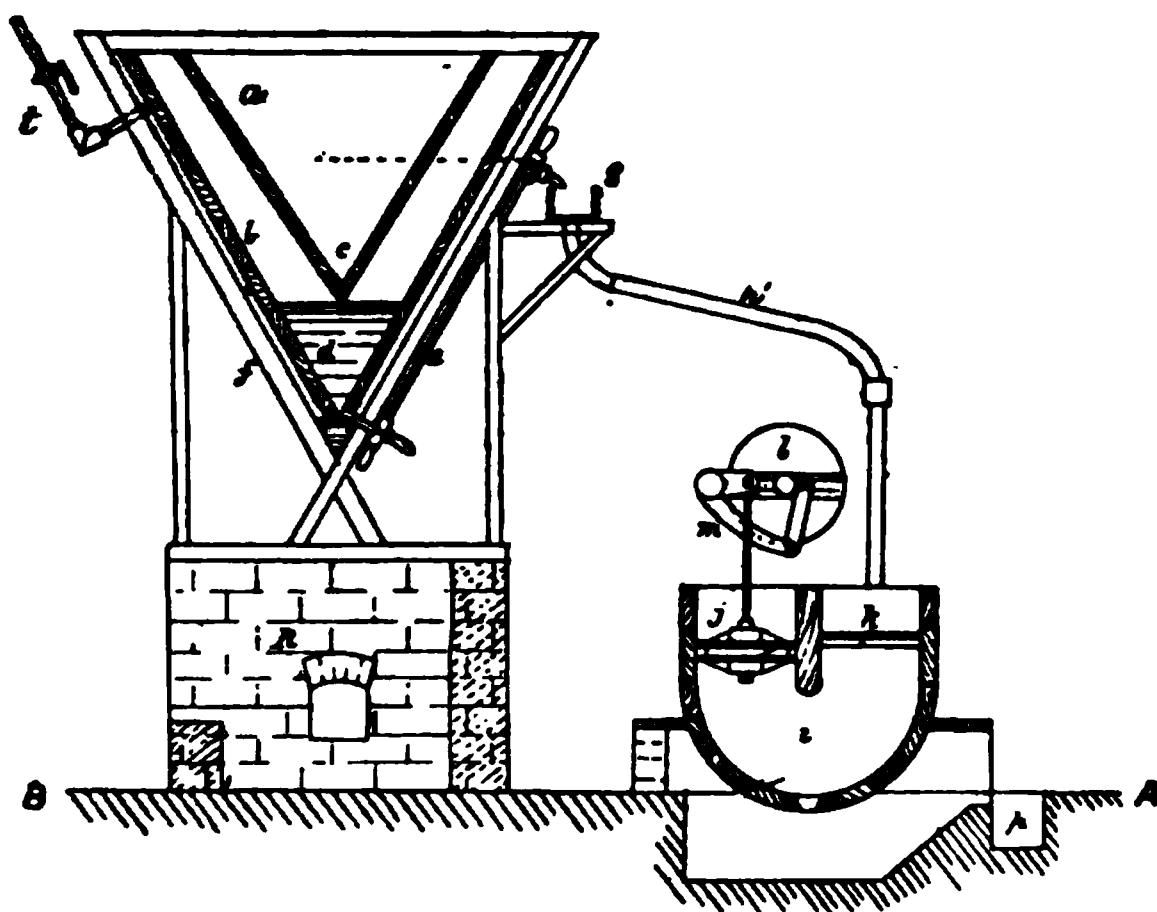


FIG. 174.—CROSS SECTION OF HYDRAULIC CLASSIFIER.

hydraulic classifiers built on the above principle. The example given is large enough to supply two or three jiggers, and may be extended at either end by following the general lines given, preserving the same inclination and angles.

SPITZKASTEN.—The fine slimes rejected by the hydraulic classifier flow on to a spitzkasten, an apparatus consisting of funnel-shaped boxes or rectangular pyramids with the base upwards, in which the sands settle, the coarsest in the first, and the finer in the second, and so on for the series.

The position of the classifier and spitzkasten are shown at *u*

id at L and v in Plates III. and IV., e it is seen immediately behind the ht. It consists essentially of a large 8 yds. long and 3 yds. wide, divided of a W, the middle portion of which is not quite so high as the outside arms; the inclination of the long sides being an angle of 50° , which is sufficient to prevent the slimes from accumulating on them. The slime waters are spread over the surface of this, the heavy particles fall to the bottom, and the light muddy waters flow away to the settling pits outside the mill.

From the points of the pyramids two pipes, as inverted syphons, lead up to a trough fixed on the outside of the spitzkasten, at a level of about 2 ft. 6 in. to 3 ft. below that of the water on the inside. From this trough a pipe leads to the ough this the thickened slimes flow

all the troughs and pipes conveying should have an inclination sufficient ted. This should not be less than arse sand, $1\frac{1}{2}$ in. to $\frac{3}{4}$ in. for medium- and $\frac{1}{4}$ in. for slime waters.

CHAPTER XIV.

JIGGERS AND JIGGING.

Hand Jigging—Primitive Jigger—Automatic Jigging—Hartz Jigger Stroke—Speed and Bedding—Eccentric Motion—Percussive Lever Motion—Elliptical Gearing—Bilharz Circular and Percussion Jigs.

JIGGERS AND JIGGING.—The ore, after having been properly sized in the trommels, is fed direct into machines called jiggers, which effect the separation of the substances—ore and gangue—which have different densities in water. These machines take advantage of the law that, if two bodies of equal volume and of distinct specific gravities are dropped at the same instant from the same height into a volume of water, the one of the greater weight will



FIG 176.—HAND JIGGING.

sink faster than the other, leaving it behind, and arriving first at the bottom. In ordinary continuous jigging machines the column of water is too shallow to allow of any appreciable separation of one grain from another by simply dropping the grains in together, and so the desired result is accomplished by subjecting such grains to a series of upward and falling—or pulsating—movements. The limits of size between which a mineral can be profitably

jigged are from $1\frac{1}{8}$ in. downwards to $\frac{1}{8}$ in. If the ore is coarser than this it requires too much power, and if finer the action of its specific gravity is lessened by friction, and the material lies too close together, so that other means must be adopted for its separation.

The earliest attempts to utilise the difference in the specific gravities of the ore and its gangue was by hand jigging, as shown in the sketch, fig. 176. It is said to have been practised in Bohemia as early as 1519. The sieve is an ordinary one, having a perforated metal or wire netting bottom; the mixed minerals were thrown into this, and were shaken and jerked up and down in a tub or pool of water, until the lead took the lowest, the

FIG. 177.—PRIMITIVE JIGGING MACHINE

blende the middle, and the sand and gravel the uppermost places. These were then removed in layers by means of a scraper. After this the sieve was attached to a frame, as shown in fig. 177, and moved up and down in a cistern or hutch by means of a system of levers. The machine, which is still in use in some parts, is worked by a woman or boy. The relation of the stroke of the lever to that of the sieve is as 4 ft. is to 8 in.

The connecting rod between the two levers either works in a slot or is loosely bolted, so as to give a jerk to the second lever.

The sieve is filled with a shovel, and emptied by scraping the contents with an iron scraper. Three classes are usually made—first, the upper layer, which is sterile gangue; then the middle, which consists of mixed lead ore or blende; and lastly, the lowest

layer of rich galena, which is clean and fit for sale. The fine sands which pass through the sieve are afterwards treated on a buddle. The modern improvement of this primitive form of jigger is the automatic machine shown in fig. 178, which is an elevation of a three-compartment jigger, shown also in section in fig. 179.

In this machine the sieves are fixed, and the requisite motion is given to the water by means of a piston working in a separate compartment by means of an eccentric.

The jigger comprises a horizontal hutch, constructed of wood

FIG. 178.—ELEVATION OF JIGGER.

or iron, which is divided into two, three, four, or five compartments, as may be required by the ore to be treated by transverse ends or partitions. A vertical partition extends down the centre from end to end, along the upper half of the compartments, and on one side of this there are a set of plungers or pistons, worked by the piston rods and eccentrics shown in the illustrations. On the other side horizontal screws or sieves are fixed, on which the sized ore is fed; the screen in one compartment being slightly lower than in the preceding one. The reciprocating action of the piston or plungers causes a regular pulsation of the water,

through the screens and the ore bedded upon them causing the according to its specific gravity. The the holes in the sieve, which are slightly the trommel which sized the mineral, h of the jigger below, from whence, at ough a hole closed with a plug valve

1 of a jigger is sometimes angular or round, as shown in fig. 179, and sometimes square, as shown in fig. 180, which shows the construction of a three-compartment Hartz jig.

A description of the *Hartz jigger*, figs. 180 and 181, will apply generally to every type of this machine. The wooden hutch, $p-p^3$ is divided into three equal parts by the divisions p^1 and p^2 , which form the three compartments of the jigger. Each compartment is again divided for half its length by the partition, f , on one side of which works the piston, e , and on the other side is the sieve, g . The lower part of each compartment, i , is brought down to a point at which is an opening for the outlet of the the driving shaft, a , is supported on provided with a fast and loose driving aried according to the speed desired. three eccentrics, b, b, b , which work the attached to the three pistons, e, e, e m the trough, h , to each compartment passes across the beds of the jiggers, sieves, g, g, g , is deprived in its passage and leaves the machine at n . iggers the holes in the sieves are less ommel which sent down the mineral, ore piles up on the beds, and would

become too thick but that, when it arrives at a certain height, it is allowed to overflow through the arrangement, *n*, into cases put to receive it. The reverse is the case with the fine jiggers. Here the holes in the sieves are slightly larger than those of the trommels, and consequently the rich concentrates pass through, and are collected in the cases, *i*, which are emptied from time to

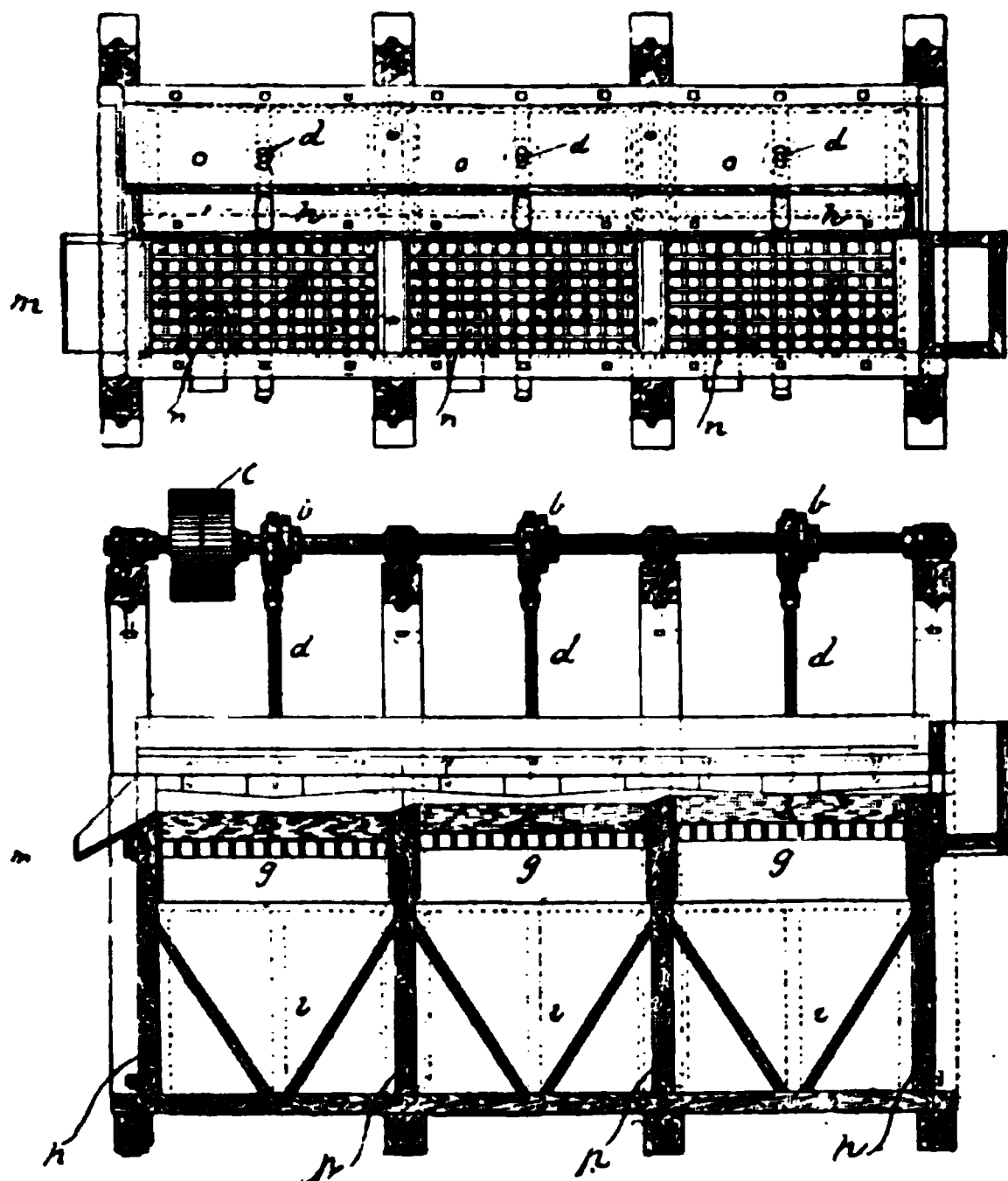


FIG. 180.—PLAN AND LONGITUDINAL SECTION OF A HARTZ JIGGER.

time by the removal of a plug in the bottom. The compartment in which the pistons work is covered with a board, *o*, to prevent the violent splashing of the water, and is lined with thin boards, which take up the wear, and save the permanent sides of the machine. In the ordinary Hartz jigger the hutch or jigger box is 3 ft. 6 in. deep, and the size of the sieves 2 ft. 4 in. \times 1 ft. 6 in.

The object in dividing the jigger into a number of compartments

is in order to obtain two or more products, as, for instance, when the ore contains both galena and blende the same jigger will effect their separation from each other, and the sterile gangue giving also a mixed product containing both the minerals, which must be sent back to be recrushed. The stroke of the piston of each compartment is regulated according to the work to be done; and for the same reason the composition of the "bed" of the jigger varies on each of the sieves. The speed also of each machine is varied according to the size of the material, the rule being the coarser the mineral the slower the speed, so that the

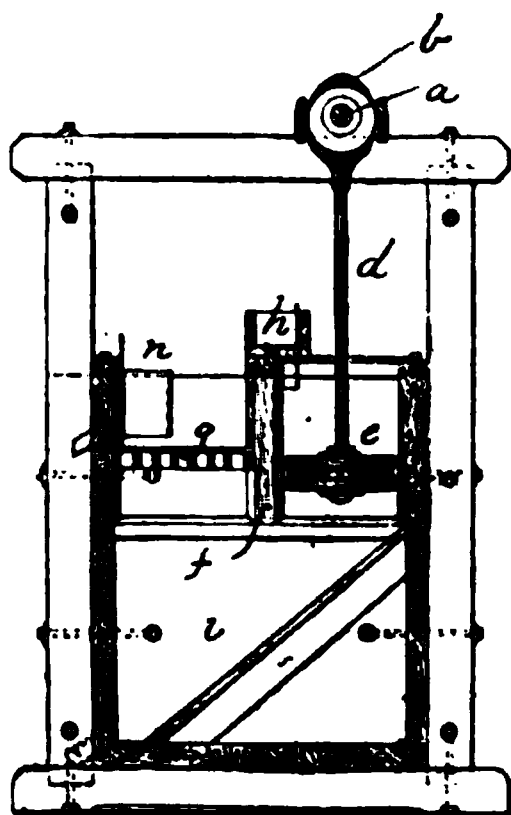


FIG. 181.—CROSS SECTION OF A HARTZ JIGGER.

speed will vary from 60 strokes per minute for 10 mm. stuff up to 300 strokes for the jiggers treating the fine sands from the classifiers. The speed at which the jigger is to run is decided upon when the mill is designed, but the stroke is adjusted by the foreman dresser or manager, according to the mineral under treatment, and the amount of enrichment which it is desired to give to the ore. As a general rule, the length of the stroke must be sufficient to lift the ore through a height equal to the diameter of the grains, and the time between the strokes must be sufficient to allow the grains to settle. The

end sought after is a stroke which will be just sufficient to lift up and open the bed of the jigger, and allow the rich grains of mineral to pass through; while, at the same time, it drives off the lighter and poorer mineral into the next compartment.

If the stroke is too great it drives the rich ore over, and the steriles contain too high a percentage of metal; on the other hand, if it is not enough, the poor stuff falls through with the rich, and the percentage of metal in the concentrates goes down.

The following table will give an approximate idea of the length of stroke and speed appropriate to jiggers treating ore from 10 mm. down to $\frac{1}{3}$ mm. diameter. These figures, however, give

only general dimensions, for practice with the kind of ore under treatment is the only way to obtain the best stroke for that ore; and once this is hit upon the jigger will run without further attention to this point.

Size of ore in millimetres	10-7½	7½-5	5-3½	3½-2	2-1½	1½-¾	¾-¾	¾-¾
Approximate length of stroke in inches	2½	2½	2	1½	1½	1	½	½
Number of strokes of piston per minute	60-100					110	120	150-300

The efficiency of the work done by a jigger also largely depends upon the state of the "beds" and the mineral of which they are composed. The bed of a jigger is the layer of ore lying upon the sieve which opens out at the down-stroke of the piston so as to allow mineral of its own specific gravity to pass through. The richness of the concentrates, therefore, will resemble that of the ore of the bed, which, in the first compartment, in the case of a lead mill, would be made of pure galena, accurately graduated as to size, being just a size too big to pass through the holes in the sieve. The products of the first case of one jigger will usually suit for the bed of the machine next smaller in the size of its sieve.

Too much care cannot be taken in order to keep the beds evenly sized and free from impurities, in the shape of large lumps of ore or stray pieces of iron, such as nuts or keys. The thickness of the bed is usually about 2 in. A thin bed means poor concentrates; a thick one makes them too rich and sends on a too great quantity of ore to the next compartment. The happy medium must be found by experiment. Attempts have been made with more or less success to use beds composed of metallic grains, such as lead or iron shots, or of an alloy whose specific gravity would be the same as that of the concentrates desired.

Iron punches and iron shot, when used for this purpose, are liable to the inconvenience of rusting into a solid mass during any stoppage. An alloy which has been used with success is made of a mixture of iron and aluminium in such a proportion as to bring down the specific gravity of the iron to that of the concentrates desired. It will be found, however, that beds composed of well-sized mineral from the ore to be treated are the best to use

and easiest to manage, though, of course, these, as all others, require frequent cleansing and renewal. The sieves are also apt to become clogged with grains of ore and must be cleared, or otherwise ; if they become much stopped, the force of the water is sufficient to tear them away from their supports.

The man in charge of a jigger should be taught to look after it, keep it in order, clean the beds and change the sieves when necessary. Unless this is done regularly there is a great tendency to leave the work of cleaning and repairing until Sunday for the sake of an extra day's pay.

The steriles from each jigger will require careful attention, especially in a newly-started mill, until the foreman is able to judge by the eye the quality both of the concentrates and steriles. For this purpose frequent assays must be made of each of the products of the machine, and especially of the steriles, by which I mean the waste mineral rejected by the jigger, containing less than 2 per cent. of metal, which may be thrown to the waste heap. The tailings or mixed mineral from the fourth and fifth cases will consist of ore over 3 per cent., which should be sent to the fine crushing mill in order that the minute grains of ore may be separated from the gangue which holds them. The mineral rejected as tailings from the coarse jiggers will, as a rule, always pay for recrushing, but the sands from the fine machines should be valueless.

The output of a jigger will vary between 5 and 10 cubic ft. per hour ; the quantity of water used will be from 6 to 12 gallons per minute, and each jigger will require about $\frac{1}{2}$ horse-power to drive. The taps supplying the fresh water must be watched, as the man in charge is usually much addicted to using an excess of water, and as the waste water from the jiggers passes on to the slime machinery, it dilutes the slimes and so makes them more difficult to deal with.

The eccentric motion so often employed for moving the piston rods is, perhaps, not the best suited for this purpose, as it gives a smooth, even up-and-down-stroke, whereas what is required is a swift down-stroke, to open up the beds, and a slow up-stroke, in order to give the ore time to settle, and classify itself. Numerous plans have been devised for this, one of which is shown in

fig. 182. In this case the driving shaft is separate from the piston shaft, which is driven by means of a crank pin on the disc of the driving shaft and the lever *a*. As the disc revolves the crank pin slides in the slot, *b*, and is nearer to the piston shaft during the down-stroke, and further from it during the up, thus producing a difference in the speed of the two strokes. An almost similar arrangement is adopted in the fine slime jigger (fig. 183); in this case, however, the crank pin does not slide in

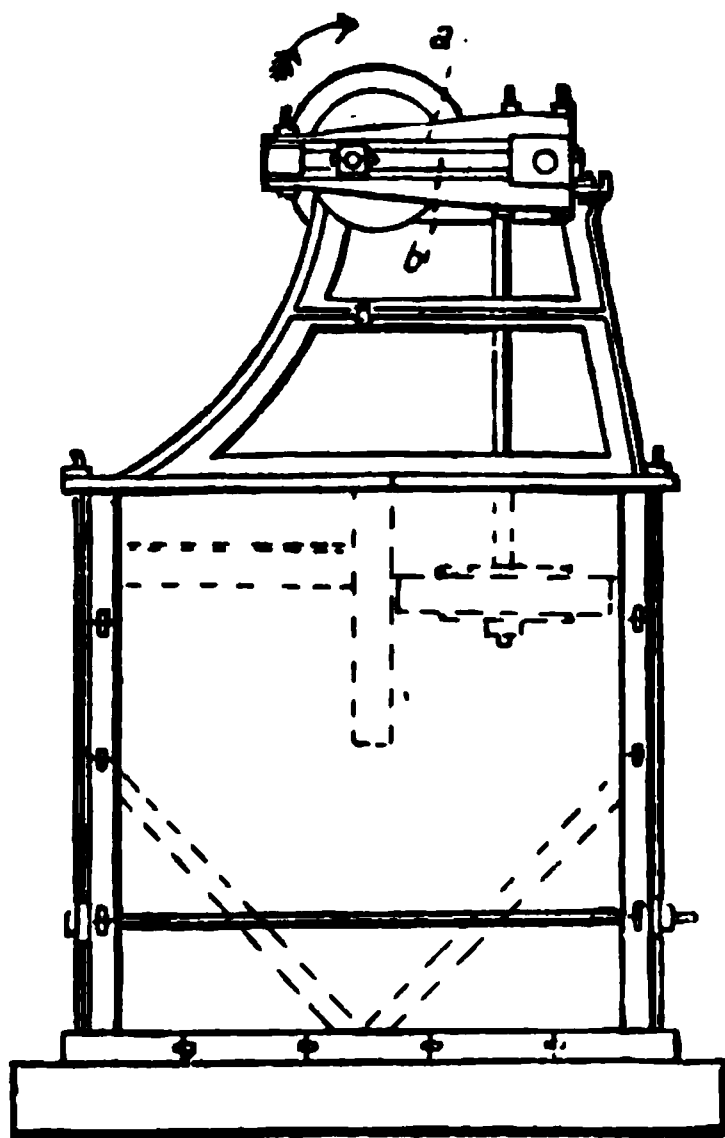


FIG. 182.—LEVER MOTION JIGGER.

a slot of the lever, but works the latter through the intermediary of a connecting rod. In both cases the result is similar, and the length of the stroke can be varied by altering the distance of the crank pin from the centre of the disc.

Another scheme for the same purpose is the use of elliptical gearing, as in fig. 184, by means of which the motion begins at a slow speed, increases rapidly and uniformly until the lowest point is reached, then gradually diminishes until the piston reaches its highest point, the result being a quick and perfect separation of

the mineral, as compared with the old eccentrics. The use of gearing of this class is objectionable, however, for other reasons, and is not to be preferred to the lever motion.

FINE JIGGING. — *Bilharz Percussion Jigs and Circular Percussion Jigs.*—In the old days of hand jiggers, illustrated in fig. 177, it was the sieve of the jig which moved, in imitation of the hand-sieve motion, which was the origin of all jiggling machines. Afterwards, when treating coarse ore with heavy beds, it was found inconvenient to

FIG. 183.—SIDE DELIVERY JIGGER, WITH LEVER MOTION.

move the whole mass of mineral, and so a plunger or piston, setting in motion the water acting against a fixed sieve, was adopted, as in the automatic jiggers shown in figs. 178 and 179. It has, however, been found when treating the sands delivered from a hydraulic classifier or spitzlutter that the old-fashioned method of moving the sieve rapidly is preferable to moving the water, and the Bilharz percussion jig is the embodiment of that discovery.

As will be seen in fig. 185, each jigger consists of one sieve hung by two arms, receiving a vertical motion from an eccentric on the driving shaft, and working in a sieve box which may be adjusted to any height in the framework, so as to allow of the box in one machine being lower than that of another when, as in the illustration, they are arranged in series.

The sieve is made of perforated copper plate or brass wire, and on it lies the bed most adapted to the size of material to be jiggled. The sieves are wider at the supply end than at the discharge, as is also the outer box or casing of the machine.

FIG. 184.—ELLIPTIC GEARING FOR JIGGERS.

Each sieve box can, if desired, be divided into two parts by means of a movable division piece, which admits of two products being made at the same time. For this purpose also the box below is fitted with two discharge openings, one of which, if necessary, remains closed.

The average stroke is about 5 mm., say $\frac{1}{2}$ in., and the speed 220 strokes per minute. The clean water supply is delivered under the sieves and is controlled by a tap.

These jiggers are designed to treat the mineral supplied by the

FIG. 185.—BILHARZ SLIME JIGGERS.

first compartment of a hydraulic classifier or spitzlutter, the stuff from the second being sent to a circular percussion (fig. 186), and that of the third to a Bilharz percussion table, as described on page 303, and fig. 194.

Bilharz Circular Percussion Jig.—In the description of the lead concentrating mill at the Neuhoof mine in Silesia, given on page 445, it will be noticed that the sands from the classifier, 1. (Plates III. and IV.), are treated partly in fine slime, or Hartz jiggers, r' , r'' , and r''' , and partly in circular Bilharz jiggers, s' , s'' . The following is a description of these circular jiggers:—

The machine (fig. 186) consists of a circular sieve, which is moved vertically by means of an eccentric at the rate of from 200 to 220 strokes per minute, the length of the stroke being from 5 to 6 mm., in a circular outer box, round at the top and cone-shaped below. The sieve is divided into a number of compartments, usually six, according to the requirements, and each

FIG. 186.—THE BILHARE CIRCULAR JIGGER.

compartment carries a bed the size and height of which are regulated according to the size of the material to be treated.

The mineral is fed on to the machine radially; the rich ore passes through the sieve as in ordinary jigs, and is discharged through a pipe at the bottom in a thick state of consistency, while the tailings pass away through a pipe in the centre of the

machine. The weight of the sieve and its contents is counter-balanced.

This jigger does not make any middle products ; the single product is the enriched and concentrated part of the classified material from the hydraulic classifier. The machine can, however, separately and simultaneously concentrate the sized products of the classifier by leading each separate size to a separate compartment of the sieve. Its weight is about $2\frac{1}{2}$ tons and price £172.

We have now passed through the processes of crushing and pulverising the ores, and concentrating them as far as can be done by the methods of coarse concentration which may be said to terminate with fine jigging. The methods adopted for the fine concentration of the pulp or slimes from all classes of mills next demand our attention, and will be discussed in the succeeding chapter.

CHAPTER XV

MACHINERY FOR FINE CONCENTRATION.

The Mixer—The Round Buddle—The Concave Buddle—The Revolving Knife Buddle—Wooden Percussion Table—Single Percussion Table, End Shake — Gilt Edge Concentrator — Rittinger Table, Side Shake — Hendy's Concentrator.

THE coarse concentration of minerals may be said to end with the process of jigging, although that of fine jigging almost forms an intermediate stage between it and fine concentration proper.

This chapter will therefore be devoted to the description of the various appliances used, either supplementary to jigging or in those cases where, as in gold, silver, and tin milling, the ore has been reduced direct to the state of pulp or slime, and proceeds direct from the stamps or other pulverisers, to the fine concentration machinery.

As a rule the milling process is a continuous one, and the water carrying the finely divided mineral is not allowed to rest and deposit its burden until it has been deprived of its valuable contents. Sometimes, however, this is not the case, and, accordingly, the fine mineral must be thinned with water before it can be concentrated. For this purpose a mixing machine is employed.

THE MIXER.—The slimes, when deposited in the labyrinths or settling pits, become hard, and must be broken up and mixed with a certain quantity of water before they can again be treated in any of the machines for concentration. To effect this purpose a mixing machine such as that shown in fig. 187 is generally used, though frequently they are home-made affairs which effect the purpose equally well. The hard slimes are fed by means of a

shovel into the hopper, together with a stream of water. Here they come under the action of the revolving blades, which break them up and send them on into the small trommel, through the holes of which they pass and out by the centre spout to the concentration machine. All chips of wood, sawdust, odds and ends of wire, nails, and so forth, are rejected by the trommel, and had best be sent away to the waste heap, before they can once more get into circulation in the mill.

FIG. 187.—THE MIXER.

The mixer revolves at a speed of 12 to 15 revolutions per minute, and is usually placed in proximity to the round buddles, or percussion tables, to which the thinned slimes pass direct.

THE ROUND BUDDLE.—The concentrating machine for slimes, which has hitherto been a great favourite, is the round buddle, shown in fig. 188, and this was perhaps due to the great simplicity of its construction, which permitted its being made out of the odds and ends of machinery usually to be found on a mine. The fixed and revolving cast-iron heads, shafting, bevel wheels, and

driving pulleys, are usually procured from a firm of machinery makers.

The buddle itself consists of a shallow circular pit formed in the ground from 14 ft. to 22 ft. diameter, and from 1 ft. to $1\frac{1}{2}$ ft. deep. The poorer the slimes the greater the diameter, and as the product from the buddle always requires re-treatment, it is usual to concentrate first in a machine of small diameter, and then to re-treat the concentrates thus produced in one of a larger diameter. The sides of the buddle pit are formed of stone or brick, set in mortar, and the floor, which has an inclination outwards of 1 in 30, is made either of smooth planed boards or cement run upon a

FIG. 188.—THE ROUND BUDDLE.

layer of concrete. The centre head is from 6 ft. to 10 ft. in diameter, and may even be less. A revolving head is fixed to the shaft, and this carries four arms. The revolving head receives the slime waters from the trough, and distributes them on an even layer over the fixed head; the liquid stream, which should be in a uniform thin film, falls over the edge of the fixed head, and distributes itself outwards over the sloping floor of the buddle towards the circumference, depositing in its passage the rich ore it contains, according to its specific gravity, the richest first, close to the fixed head, and the poorest at the circumference. To each of the four arms a board is attached, carrying a cloth or a series of brushes, which sweep round and smooth out each successive

layer of mineral as soon as it is formed. In some cases sprays of fresh water are used instead of the cloths or brushes, the number of revolutions in either case being 3 or 4 per minute.

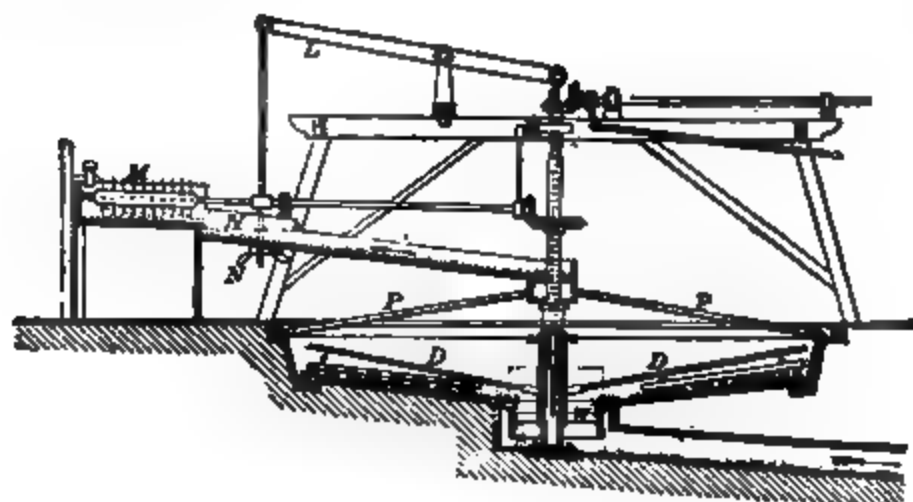
The outflow of the waste waters takes place through the small sluice gate shown in the circumference of the buddle. In the door of this sluice is a vertical line of holes, and, as the layer of mineral thickens on the floor, a plug is placed in the lowest hole, and so successively up the series, until the full thickness of the deposit equal to the height of the cone is reached. At this point the machine is stopped, a groove is cut from the cone to the circumference, and samples of the ore are taken and washed on a vanning shovel. By this means an idea is formed as to where the divisions should be made; for at the head the concentrates are rich in galena, and then follow the mixed ores, either of galena, blende, and gangue, if blende is present, or of galena and gangue, if it is absent. Two qualities of the mixed ores are formed. Rings are formed around the deposit on the buddle to indicate the division lines. The rich heads are taken out and reworked once in another buddle, when they will be rich enough to be sent to the dolly tub (figs. 201—203). The middles are likewise re-treated, the ores of approximately the same percentage being treated in the same machine until all the mineral is abstracted, and the waste contains not more than $\frac{1}{2}$ per cent. of lead, and 1 to $1\frac{1}{2}$ per cent. of zinc. By successive re-treatment the minerals may thus be enriched up to 50 to 60 per cent. Pb., and when blende is present, to about 42 per cent. Zn. These concentrates may either be sold as they are, or further enriched in a dolly tub.

The great drawbacks to the round buddle are the facts that no clean products can be made straight away. The mineral must be handled several times, always a costly proceeding, and the machine must be stopped when full, and lie idle until emptied. A large number of buddles are always required to cope with the slimes from even a small mill; that shown in fig. 265 would require three or four, while in large mills, especially when blende is present, from sixteen to twenty would be needed.

THE CONCAVE BUDDLE.—The buddle which has just been described, might also be appropriately called a convex buddle,

seeing that the centre is higher than the circumference, and in contradistinction to this we have Borlase's concave buddle, shown in fig. 189, in which the circumference is higher than the centre where the discharge takes place.

The buddle is suitable for the enriching of the heads of the



Section.

Plan.

FIG. 189.—THE CONCAVE BUDDLE.

round buddles, which may be broken up and thinned in the mixer, M, and be deprived of any coarse, foreign matter, by the screen, N. For this purpose the mixer, shown in fig. 187 and previously described, is particularly well adapted.

The ore is fed by means of the trough, N, into the centre of the machine, and is conveyed thence to the circular circumferential

edge of the buddle, by means of the six revolving spouts, *p*, from which it flows uniformly over the conical sloping floor towards the centre, *h*. The slope of the floor is about 1 in 12. The greatest proportion of the ore is deposited round the circumference of the floor immediately under the circular ledge, while the waste waters flow over the top of the rising ring into the well, *h*, and away to the settling pits.

Formerly, instead of the rising ring, *h*, a fixed one, having holes and plugs, was in use, the plug being inserted as the thickness of the concentrates increased. In the more modern machines, however, the ring, *h*, is made to slide, and its edge may be raised by hand, by means of the rod and lever, *L*, carrying with it the sweeps, *D*, which are thus kept at the proper height by the same adjustment. By this means the height of the outflow is adjusted more gradually and uniformly than by means of the plugged holes, while there is less liability of waste from the guttering of the surface of the concentrates.

THE REVOLVING KNIFE BUDDLE.—The ordinary flat buddle, which consists simply of a gently-sloping floor of boards upon which the ore to be concentrated is shovelled or brushed against a stream of water, which carries away the lighter particles, and so enriches the mineral, is doubtless the forerunner of the automatic revolving knife buddle, which was brought to its present form by Captain T. Ball, of the Goginan mines in Cardiganshire, and has been worked with great success in the Welsh lead mines, especially as a concentrator of heavy ore, associated with a light gangue, such as galena and carbonate of lime, or of coarse-grained oxide of tin, mixed with fine-grained quartz ore sand.

The machine consists, as will be seen from fig. 190, of a cylindrical frame, $9\frac{1}{2}$ ft. long \times 6 ft. diameter over all, rotating on a horizontal axis, and carrying a series of scrapers or knife blades, arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet iron, but without touching it. The casing forming the bottom of the buddle, extends rather less than one-quarter round the circumference of the revolving frame, as shown in the illustration. The ore in the state of slimes is supplied at one end of the buddle from the hopper, *A*, or from a mixing machine, and is made to

traverse gradually along the whole length to the other end, F, by the propelling action of the revolving knives, which are fixed obliquely, and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water from the launder, D, flows down over the whole curved slope of the bottom of the buddle, and the minerals are gradually propelled to the

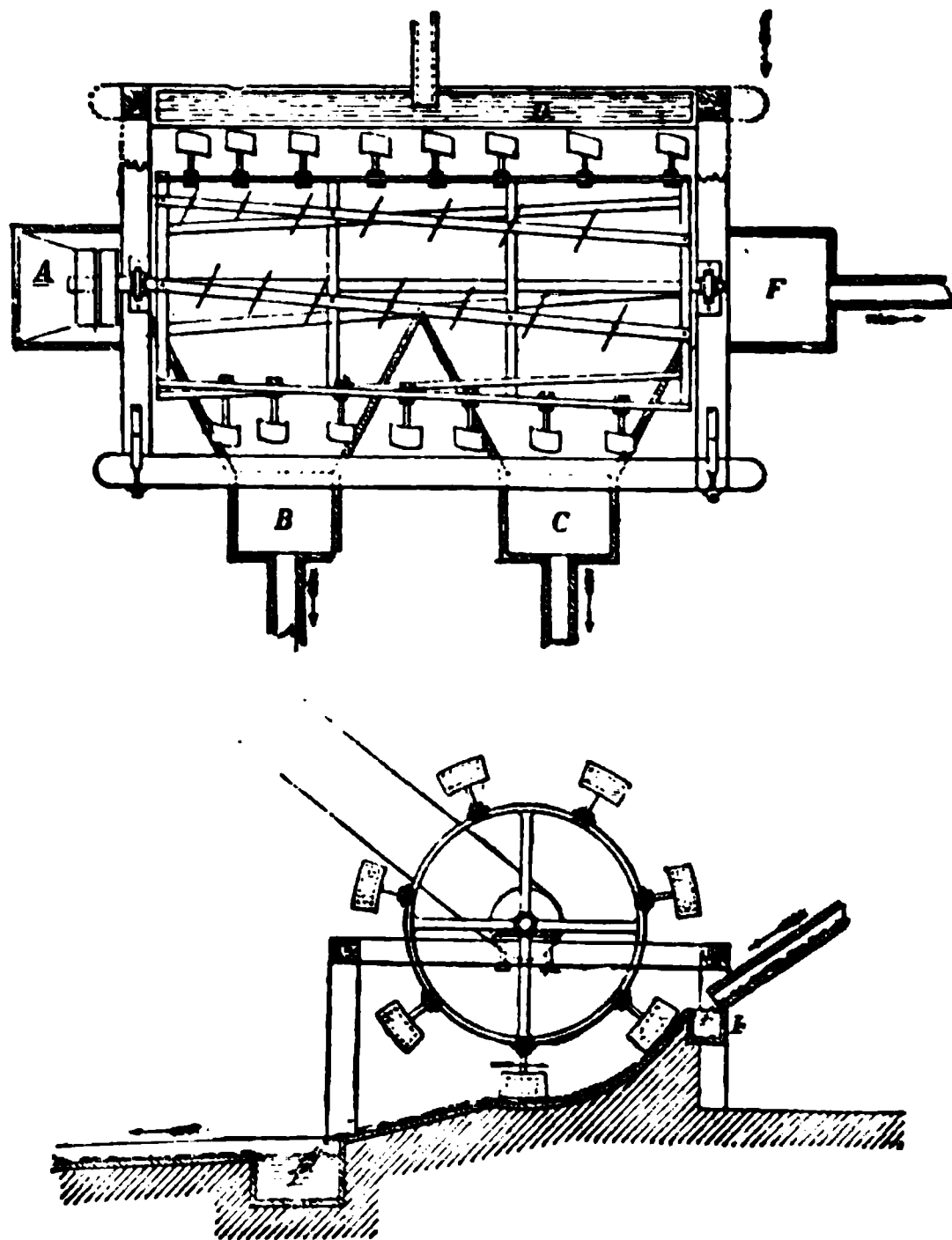
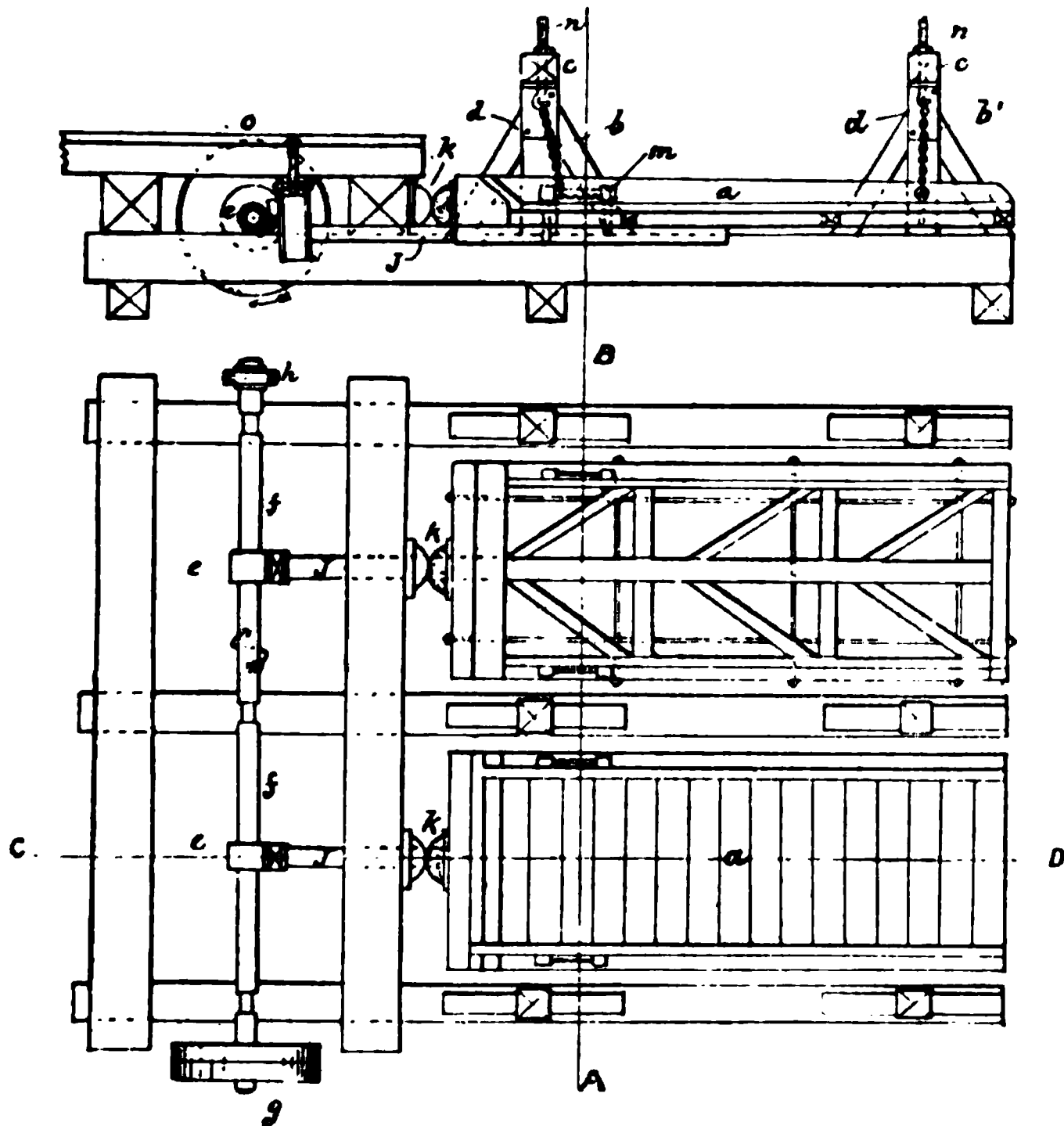


FIG. 190.—THE REVOLVING KNIFE BUDDLE.

further end, where they drop, as concentrates, over the edge into the case, F. The machine is driven at the rate of about 20 revolutions per minute, giving the knife blades a velocity of about 370 ft. per minute. The action of the machine is found to be very perfect, the whole of the stuff being continually turned over by the knife-blades, and pushed against the descending stream

of water, which washes out the lighter particles into the cases, B and C. The result is a very complete separation of coarse-grained tin ore in a single operation, with but a small loss in the

FIG. 191.—SECTION ON LINE CD.



SCALE 1/40"



FIG. 192.—PLAN OF A DOUBLE PERCUSSION TABLE.

waste. The contents of the first waste case, B, which contain a small percentage of tin, can be passed through the buddle a second time ; but those of the second case, C, are usually too poor for further concentration.

At the Lisburne mines, in Cardiganshire, the quantity of stuff treated by one of these machines was $2\frac{1}{2}$ tons per hour; the crude ore sent to the buddle contained about 15 per cent. Pb., and the concentrates obtained were of 50 per cent. Pb. By re-treating these latter they were further enriched up to 75 per cent. Pb. The crude ore contained quartz blende, carbonate of lime, slate, and lead ore.

WOODEN PERCUSSION TABLE.—The situation of some mines, with regard to transport, is often such as to prevent the use of a piece of machinery, owing to its price being enormously increased by the cost of carriage. In these cases the manager endeavours to manufacture, on the spot, some of the minor appliances used in concentration; and it is with this end in view that I give the annexed drawings (figs. 191—193) of a double percussion

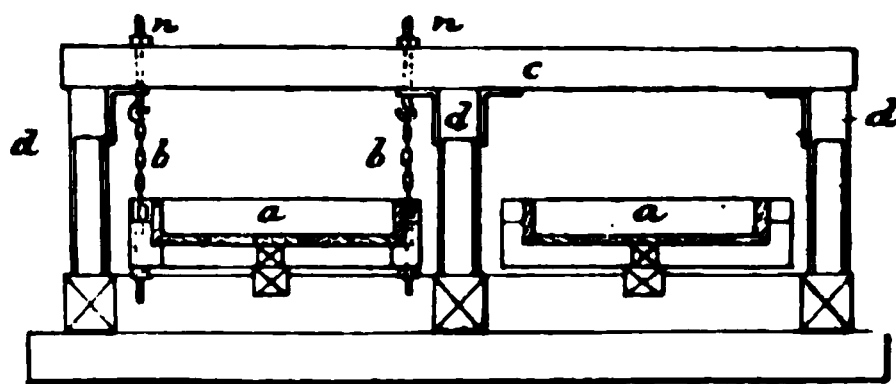


FIG. 193.—CROSS SECTION OF DOUBLE PERCUSSION TABLE.

table which I have found to work with great satisfaction on ores containing lead and blende, and which would doubtless answer equally well for the concentration of pyrites and other minerals.

With the exception of the shaft, pulleys, and cams, the whole is made of wood bolted together with such ironwork as the local blacksmith can make. The machine can be made either with one or two tables, as may be desired.

Each of the tables, *aa*, has an area of 11 ft. 8 in. \times 4 ft., and is slung by the adjustable chains, *bb'*, from cross bars supported by means of the stayed uprights, *dd*.

The percussion is given to the table by means of the rods, *jj*, which are forced back about two inches by means of the cams, *ee*, fixed on the shaft, *f*, and driven at the rate of about 80 revolutions per minute by the pulley, *g*.

At the end of its stroke the cams, *e*, release the rods, *jj*, and the tables fly back against the buffers, *k k*, one of which is of iron and the other of wood. The table is slung by the chains, *bb'*, the latter of which hangs perpendicularly when the table is at rest; but in order to give force to the blow, the chains, *b*, can be notched up in the rack, *m*, according to the amount of force required.

The slope of the table can be varied by means of the

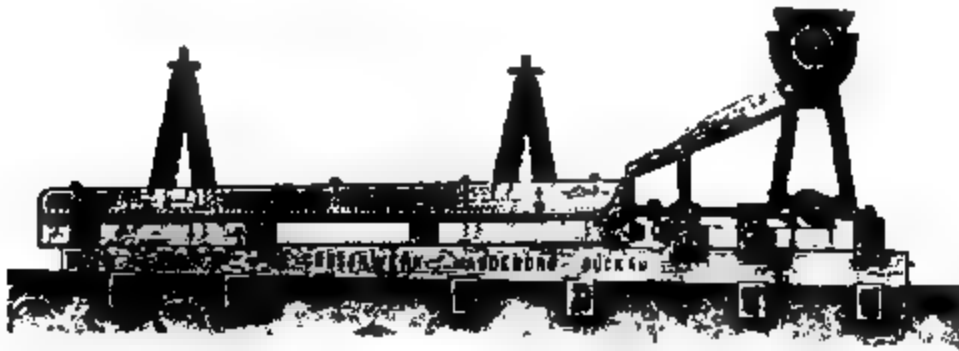


FIG. 194.—SINGLE PERCUSSION TABLE.

hanging screws, *n, n*. A mixer is fixed on the platform, *o*, driven from the small pulley, *k*, the ore diluted with the necessary quantity of water is fed on to the head of the tables by a shoot which spreads it over the full width of the table.

The drawings are to a scale of $\frac{1}{16}$ th, and the under framework of the table is shown in the plan, fig. 191.

The surface of the table should be quite smooth, and the whole of the timber employed should be well seasoned.

The Single Percussion Table shown in fig. 194 is of less

primitive construction than the one just mentioned. The table is of wood, and is slung by means of chains from cast-iron supports, the inclination being adjusted by means of the hand wheels. The blow is given by the recoil from the cam on the driving shaft, which also drives the mixer fixed at the head of the table. This mixer is the same as that shown in fig. 187, and the ore to be concentrated, after being fed into the hopper, is broken up and diluted to a proper consistency with water by means of the revolving knives. All coarse foreign matter is rejected by the small trommel, and the slimes are spread evenly over the surface of the table by means of sloping board at the head, on which are fixed diamond-shaped directing pieces. It is of great importance that the slimes should be spread in an even sheet over the full width, as otherwise the water is apt to cut channels through the mineral accumulated on the table and sweep it off, if not carefully watched. The speed should be such as to give about 80 blows per minute, that of the mixer being about 20.

The power absorbed will be from $\frac{1}{2}$ to $\frac{3}{4}$ horse-power for a single table, or 1 horse-power for a double, while the amount of work done will altogether depend upon the richness and consistency of the slimes fed into the machine. In order to regularise the speed a heavy flywheel is sometimes fitted to the driving shaft, and improves the working of the machine.

Some firms make the whole appliances of cast and wrought iron; but where ease of transport has to be considered it is better, perhaps, to buy only the necessary iron fittings, and make the remainder of the machine of wood from the drawings which will be supplied with them by the makers.

GILT EDGE CONCENTRATOR (PERCUSSION TABLE).—The percussion tables already mentioned are excellent machines and capable of doing good work. Their chief defect is that they are not continuous in their action, and do not deliver the products as they are separated, but, owing to their construction, must of necessity allow them to accumulate on the surface of the table until the latter becomes as full as it will hold, when the machine must be stopped in order to be unloaded of its concentrates. The inventive power of the American machinist overcame this difficulty by removing the board at the top end of the table, and

allowing the concentrates to fall over the edge into a collecting case below. This necessitated some structural alterations in the machine, which will be seen in fig. 195. The tables are made of cast iron with a shallow border, and curve up slightly towards the upper end in addition to the usual inclination allowed; and then the plate turns downwards on a sharp curve, over which the concentrates (which, by the action of the repeated blows, have travelled upwards) fall into suitable receiving cases. The steriles are washed to the lower end, and are carried away by the stream of water to the outside of the mill.

This machine is well adapted for treating auriferous pyrites, or any ore containing only one mineral and the gangue, because,



FIG. 195.—GILT EDGE CONCENTRATOR.

owing to its construction, it will only separate into two classes—rich and sterile. In this respect it is inferior to the old form, which will separate two minerals from the gangue, as, for instance, galena and blende from quartz.

HENDY'S CONCENTRATOR.—A concentrator which has met with some favour as an enricher of the pulp from a stamp battery in a gold mill is that known as Hendy's. The pulp, after having passed over the amalgamated copper plates, and been deprived of whatever free gold it contains, is sent on direct without classification to a Hendy, which concentrates the auriferous pyrites, and prepares them for the subsequent roasting and chlorination. It would also treat other metalliferous ores in the same manner;

but if clean concentrates are desired those obtained from four machines should be sent on to a fifth, where the process of concentration will be completed.*

The machine is shown in fig. 196, and consists of a shallow pan, 5 to 6 ft. in diameter, supported by a vertical shaft in the centre. the pan being made to oscillate by means of cranks on

of the pan, and so the slimes are evenly distributed over the whole surface of machine. The distributor, *d*, also carries rake-shaped arms, which continually stir up the concentrates as they settle to the bottom. The crank makes 210 revolutions per minute; and the accumulated pyrites are discharged through the opening, *e*, while any amalgam or mercury collects in the hollow, *j*. One machine will concentrate 5 tons of tailings in 24 hours.

CHAPTER XVI.

FINE CONCENTRATION MACHINERY (continued).

Evans' Slime Table—The Linkenbach Table—Brunton's Cloth.

EVANS' SLIME TABLE.—The inconveniences attendant upon the old form of round buddle, as already described, induced men of an inventive turn of mind to experiment with a view to perfecting the machine, and one of the forms which has met with success is the Evans' slime table, shown in fig. 197, and also a buddle known as J. Collom's, which is a variation of Evans' table. The slimes from the mixer or classifier are brought to the distributor, B, by means of the launder, A. The distributor is divided into two parts by means of the partition, *a*, in order to separate the clear water supplied by the pipe, *d*, from the slime water. The clear water runs over half the table, while the slime water flows over the other half, the two being kept from mixing by means of the division plate, L. The slime water on one side of the distributor, B, runs through its perforated bottom, and is distributed evenly over one-half of the stationary head, C, and runs on to the rotating table, D, the waste water and steriles falling over the edge into the circular launder, N, and through the waste pipes, O O, to the settling pits; the rich mineral, however, clings to the upper part of the table, D, and is shielded from the action of the clear water by means of the cone-shaped head, C, while the mixed grades are washed about halfway down the rotating table, D, and as the table rotates come under the action of the spray, E, which washes them off into their case, J, through the circular launder, N, and the pipe, K. Lastly, the rich concentrates are played upon by the strong jet, F, and washed off into

the case, H, through the pipe, I. The conducting board, G, also helps to prevent any of the rich ore being carried on and mixed with the fresh supply of slimes arising on the table, D.

The second class ore in the case, J, can be rewashed. The head, C, is suspended from the frame, M, so that it can be readily adjusted relatively to the table, as may be required. It will be seen that the action of the table is continuous, and that no mineral is allowed to accumulate upon it. The machine, therefore, can be kept constantly at work without any loss of time for clearing, as is the case with the ordinary round buddle.

The arms and segments should be made of hard pine, about half seasoned. The surface of the table should be of soft pine,

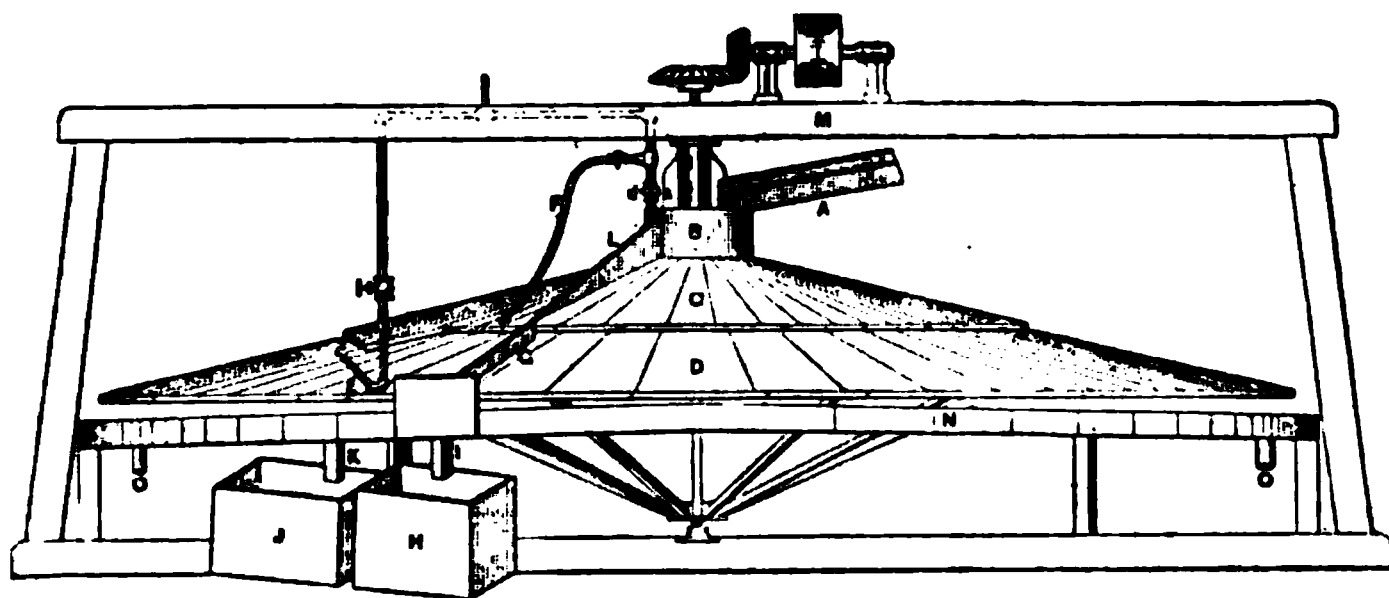


FIG. 197.—EVANS' SLIME TABLE.

and must be green and perfectly clear, true, and uniform. The diameter is about 14 ft., and the boards must be tongued and grooved. The speed of the machine is about one revolution in 80 seconds, and the inclination of the table is $1\frac{1}{4}$ in. to a foot, that of the head being $1\frac{3}{4}$ in. to a foot. The capacity is from 25 to 30 tons per day of 24 hours, depending upon the fineness of the material worked, the gravity of the ore, and the degree of concentration effected.

One of the disadvantages of the rotating type of buddle is that owing to its large diameter a perfectly even motion, which is a desideratum, cannot be obtained; or if the motion is regular it is at the expense of a loss of diameter, whereas a large diameter is essential to the proper classification and concentration of the

minerals. An improvement again upon the Collom buddle is the Linkenbach rotating table, a machine capable of doing excellent work, of which I can speak from personal experience. The rotating Linkenbach, however, was limited as to its diameter by the necessity of an absolutely regular and uniform motion, so that it, in its turn, has been superseded by the fixed Linkenbach table, made of masonry faced with cement. I therefore pass over the rotating Linkenbach, which can be used with great advantage where the space is confined, to the fixed table, which may be made of any reasonable diameter of from 6 to 10 metres, and which, as a concentrating machine for fine slimes, I have found to give perfect satisfaction.

THE LINKENBACH TABLE.—The treatment of the slimes from a large concentration mill is always one of the most difficult points to be decided, and, as will be seen from the immense number of machines which have been patented for this purpose, it is one to which serious attention has been paid by many talented men. In the end of the year 1885 I was engaged in studying this matter previous to erecting machinery for the purpose of treating the slimes from a lead mill at a mine in the South of France, and in the course of my investigations visited a large mine near the city of Ems, in Germany, and there saw the Linkenbach tables at work on a large scale ; in fact, their inventor was at that time the manager of the mine. After having examined other types of machinery, as employed in various mines in Germany, I decided upon the use of the Linkenbach table for the works over which I was manager in France, and have never regretted my choice.

The original Linkenbach table consisted of a cone-shaped table of some 2 or 3 metres diameter, made of iron, and revolving underneath a system of jets. The slime water was fed over the centre of the cone, and as it ran down to the edges deposited the mineral matters according to the specific gravity, and these were afterwards swept off by the sprays of water under which the table revolved.

The difficulties with this class of table were to obtain a sufficiently large diameter, and an absolutely smooth motion. In order to get over these the inventor designed a fixed table made

of concrete, while the light arms revolved on a framework. A general view of a table is shown in fig. 198, while a plan and section are given in figs. 199 and 200.

The table can be made of any diameter up to 10 or 12 metres, and must be built on well-settled firm ground, so as to avoid any danger of subsequent subsidence, which would alter the slope and crack the smooth cement face of the machine.

Having decided upon a suitable spot, a trench is dug, and the tunnel, *o o*, of fig. 199, is constructed and arched in brickwork. This tunnel terminates in a well, *o*, which forms the centre of the table directly under the cast-iron buddle head, *p*, and the utility of this arrangement is that it permits the pipes conveying the slime waters, *n*, fig. 199, to be fed into the buddle head, *p*, and also allows access for lubricating to the bearing at the foot of the vertical shaft, *p*.

The table is first roughly constructed in brickwork or concrete, and over this a smooth layer of hard cement. The slope is usually about 1 in 12. The channels, *g*, of which there are four surrounding the table concentrically, receive the concentrated mineral which is swept off the surface of the table by means of the sprays, *e*, into the circular revolving channel, *f*. The mineral is conveyed from the cement channels, *g*, by means of small wooden troughs to the various settling tanks, *q*¹, *q*², *q*³, *q*⁴. The revolving receiving channel, *f*, is divided by partitions into four parts, from each of which a short spout, seen in the section, conveys the mineral into one or other of the cement channels, *g*.

A light iron framework, *h h*, fixed to the shaft, *b*, which is driven by the worm gearing and shafting, *k*, supports the iron channel, *f*, as well as the arms and water sprays, *d*, *e*. The supply of clean water arrives by means of a pipe, *c*, into the centre of the shaft, *b*, and thence to the sprays, *e*, as well as to an annular spray, which partly surrounds the buddle head, *p*, as will be seen by the dots, which are shown on the right hand half of the buddle head in fig. 200. The function of this spray is to drive the lighter mineral matters down the slope of the table while that of the others is to wash them off into the channel, *f*, and so on into the cement channels, *g*, into the settling tanks, *q*.

The action of the machine is as follows:—The slime waters

arrive from the spitzkastens or classifiers by means of the pipe, *N*, and are fed into the buddle head, *F*, from whence they flow through a horizontal slot over the surface of the table immediately behind the arm with four sprays, *E*, which, as seen in the section, is advancing towards the reader; the arms, as seen in the plan, turn to the left, in the reverse way to the hands of a clock, and at a speed of about one revolution in $2\frac{1}{4}$ minutes. The light sterile slimes immediately rush down the table and over the edge into one compartment of the revolving channel, *F*, thence by

FIG. 198.—THE LINKENBACH TABLE.

means of a spout into one of the fixed channels, *G*, and away to the settling tank, *Q*⁴.

The mixed products, however, are deposited on the way; the lighter ones near the edge of the table, and the richest up near the buddle head. The arms sweep round, and first the mixed product and then the second quality lead, or the zinc, if any is present, are swept off by the sprays into their respective channels and tanks; and finally the arm, *E*, with four strong jets, comes round and clears the table of all that remains, which in the case of

galena is an ore containing 50 per cent. Pb., rich enough to be sent direct to market.

FIG. 199.—SECTION OF THE LINKENBACH TABLE.

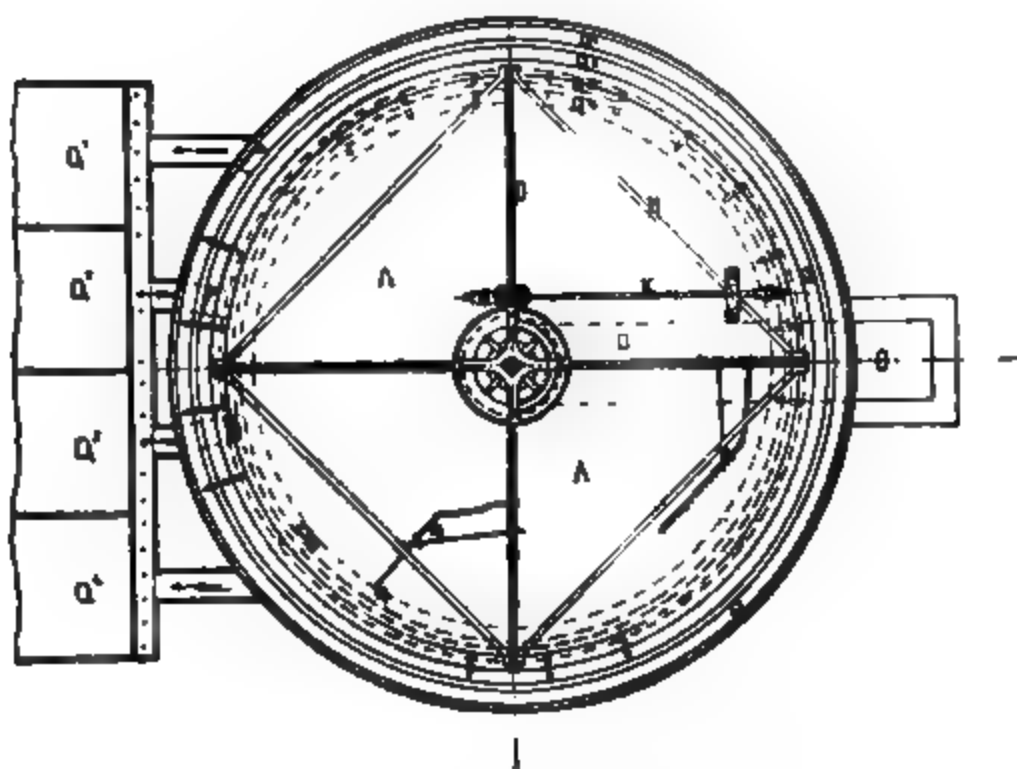


FIG. 200.—PLAN OF THE LINKENBACH TABLE.

The action of the machines is continuous and automatic. The

chief points to be observed are a uniform speed, a constant and regular pressure of fresh water, and a constant supply of slimes. Once these are given and the taps adjusted the machine requires no further attention, but will go on separating the slimes day and night with the regularity of clockwork. The only manual labour required is to empty the settling tanks, Q , as often as they are filled. The steriles will contain about 0.5 per cent. Pb.; the mixed products from Q^3 can be re-treated over the table, or, better still, upon a percussion table; while if no zinc blende is present, the two cases, Q^1 and Q^2 , can be mixed and sent to the magazine, and will contain about 50 per cent. Pb. If there is much silver in the ore, it is not advisable to concentrate to such a high percentage, owing to the loss of the precious metal which is certain to occur. The exact limit can only be ascertained by assay and experiment.

The price of the framing, tubing, and gearing, together with all the taps and connections, shafting, etc., at Cologne, is approximately as follows :—

Diameter of Table.	Marks.	£
6 metres	2900 ==	145
7 „	3200 ==	160
8 „	3500 ==	175
10 „	4600 ==	230

With regard to the amount of slimes which one of these tables is able to treat, the following information relative to the three machines I saw working at Ems will be of interest :—In every 10 hrs. the table No. I. received from the spitzkasten No. 1 7230 kilos. of solid matter; table No. II. received 5160 kilos. of solid matter from No. 2 spitzkasten; table No. III. received 1650 kilos. of solid matter from No. 3 spitzkasten. The amount of slimes running into the first spitzkasten was 453 litres, containing 23.93 kilos. of solid matter per minute, while the amount overflowing from No. 3 was 228 kilos. per minute, containing 0.62 kilos. of solid matter; so that the total quantity of solid matter treated for 10 hrs. by the three tables was, in round numbers, 14,000 kilos. (14 tons). In most mills one single table would suffice for treating the whole of the coarse slimes, and so the third table

only receives the insufficient quantity of 1650 kilos., whereas it could treat three times as much.

Supposing, however, that there was a sufficient quantity of slime waters to supply three tables, then the maximum amount they would be capable of treating would be as follows:—No. I. table, 10,000 kilos. ; No. II. table, 7500 kilos. ; No. III. table, 5000 kilos. With regard to the coarse sands of the mixed products, it is wiser to treat these apart on a percussion or shaking table, and not to send them back again to the tables. In some cases they can be sufficiently enriched by means of a dolly tub.

Perhaps the only inconvenience to be urged against the use of Linkenbach tables is the space they occupy, and the absolute necessity of having a solid foundation, for the least settlement of the ground would at once throw the whole arrangement out of gear, and probably crack the surface, which should be absolutely smooth, so as to offer no obstacle to the clean sweep of the mineral across it.

TOSSING OR DOLLY TUB.—One of the best appliances for enriching the second quality slimes from the Linkenbach tables or buddles is the tossing or dolly tub, which, indeed, is of so simple a construction as to be readily made on the mine.

In its least complicated form it consists merely of a strong oaken tub, about 36 in. deep, 30 in. diameter at the bottom, and 36 in. at the top, as shown in fig. 201.

About 8 in. below the top a strong iron ring is fixed, which receives the blows of the bars, *d*, of which there are two, each worked by a man, who places the point in a hole in the floor and strikes the ring at the rate of from 80 to 100 blows per minute. Each bar is bulged out into a ball at the point where it will strike the ring. Inside the tub is a wooden dasher, *c*, turned by the handle, *a*. At the commencement of the operation the tub is filled about one-fifth full of water, and then one man slowly fills in the slimes while two others turn at the handle at the rate of about 40 revolutions per minute. The slimes are thus well mixed up, and when the tub is nearly full the dasher is rapidly removed, and the men commence to tap with the bars ; thus hastening, by the vibration, the settlement of the rich heavy slimes. After the tapping has been continued for some time

the slimes settle down and are then dug out with a spade. The section, fig. 202, which is from a long series of trials made by myself, will give an idea of the way in which the contents have been enriched. At the bottom is a thin layer of coarse-grained slimes, which is not so rich as the interposing one, and that again is hardly so rich as the one above ; after which, the quality rapidly falls off, until at the surface there is only a layer of barren sand.

If the slimes have been subject to a perfect classification before tossing, the richest will be found at the bottom ; but as a general rule the presence of some coarse, badly classified slimes will usually prevent this ; which, after all, is immaterial, as the bulk of the ore is sufficiently rich to be sent to the magazine. The second quality can be re-treated as may be desired.

In its primitive form the tub is not an economical arrange-

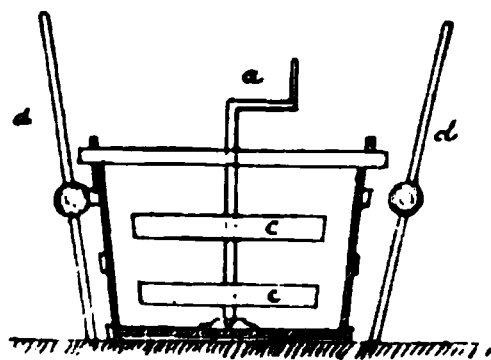
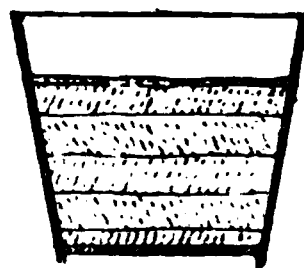


FIG. 201.—TOSSING OR DOLLY TUB FOR HAND-POWER.



—Surface 1" Sterile.
—4" Pb 7.66 %.
—4" Pb 29.88 %.
—4" Pb 58.50 %.
—4" Pb 55.96 %.
—2" Pb 44.40 %.

FIG. 202.—SECTION OF CONTENTS.

ment, as it requires too much labour ; and the arrangement shown in fig. 203 will be found not only less expensive, but more effectual, as it permits of the tapping being carried on at the same time as the loading and stirring. In my own case I found that the combined tapping and stirring made a difference of 8 per cent. in the quality of the products.

The tub itself is the same as before, but is mounted on wheels running on a short line of rails, the object of which is to allow of the tub being run from under the gearing for the purpose of being emptied.

On the horizontal shaft, *a*, a double cam, *b*, is fixed which rocks the two levers, *c c*, and so causes the ball-shaped hammers to strike the ring at the rate of some 80 blows each per minute.

The dasher, *d*, revolving at a rate of about 40 per minute by

means of the bevel wheels, *h*, is readily removable; all that is required when the loading is finished is to depress the handle, *f*, which raises the clutch, *e*, and allows the dasher to be lifted out. The tapping is continued until the slimes have settled down, and then the machine is stopped and the tub pushed from under the gearing for the purpose of being emptied.

The slimes can be enriched by this means up to any requisite percentage without any loss of silver, as but very little water is used, and that does not flow off continually, but is allowed to settle before being drained away.

BRUNTON'S CLOTH.—The Frue Vanner about to be described in

FIG. 203.—DOLLY TUB WORKED BY MACHINE POWER.

the next chapter is the latest and most perfect development of a principle which had long been experimented with in Germany and England, that of the Brunton cloth. The original machine, illustrated in figs. 204, 205, consisted of a revolving belt of coarse canvas, *a a*, stiffened with paint, and strengthened and kept level across the face by means of laths of elm, a few inches apart.

The cloth moves over a flat boarded surface, *b*, supported on a frame which is inclined at an angle of about 1 in 6. This inclination can be adjusted by suspending screws at the bottom of the frame. The cloth passes over the top roller, *d*, and is allowed to dip under the surface of the water in the collecting

tank, *f*, then up and over the roller, *d*, and back to the surface of the table by the foot roller, *e*.

The cloth travels upwards at the rate of about 15 ft. per minute. The slime waters arrive at *h*, and are spread evenly over the face of the cloth. A stream of clear water, arriving by a spray at *i*,

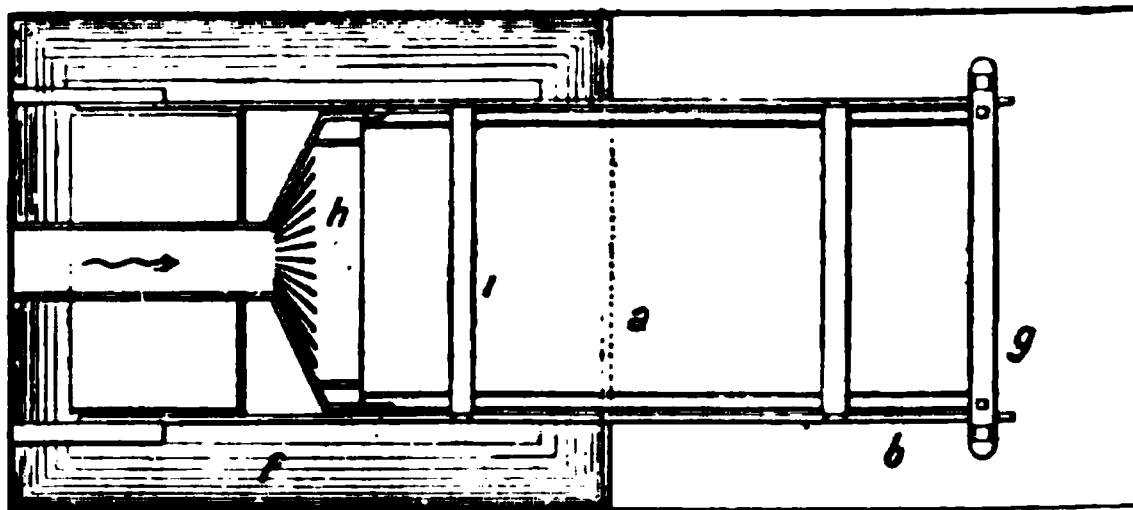


FIG. 204.—BRUNTON'S CLOTH. PLAN.

has sufficient force to carry away the light particles; but the greater adhesive power of the grains of ore enable them to withstand it, and they remain attached to the cloth until they are carried over the roller, and under the surface of the water in the tank, *f*, when they fall to the bottom.

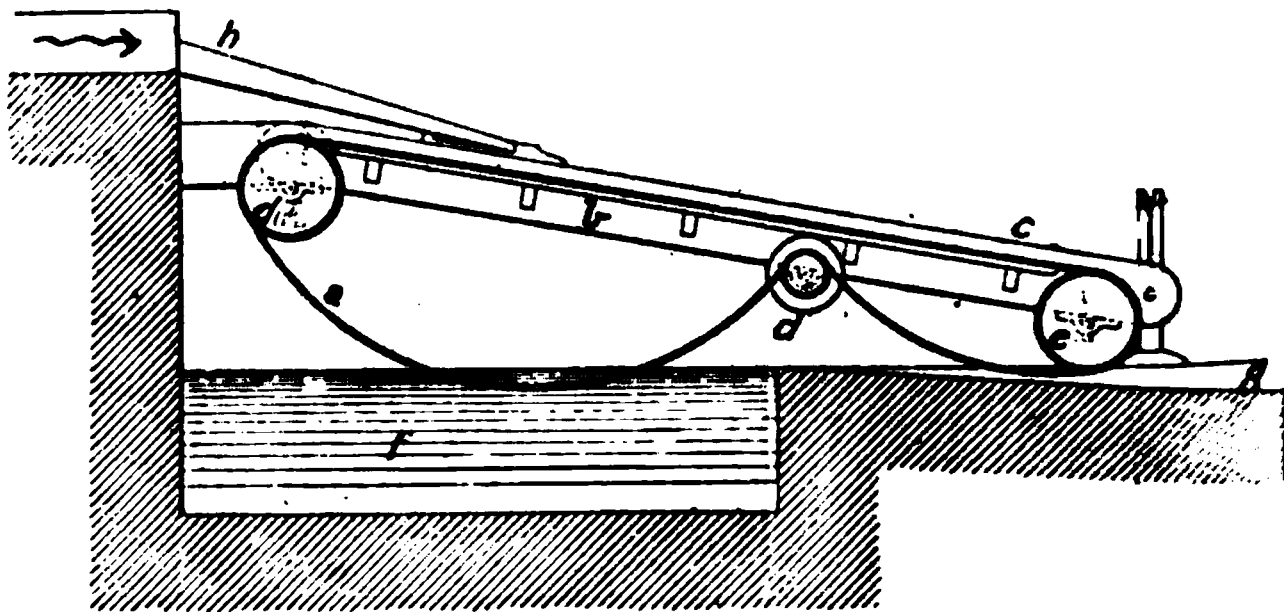


FIG. 205.—BRUNTON'S CLOTH. SECTION.

There are three adjustments to make for treating different nature of stuff—viz., inclination of the belt, rate of movement, and quantity of clear water admitted. The apparatus, as generally used, is fairly efficient, and its construction is so simple that it can be made on the mine. On the German dressing floors its

efficiency is increased by giving it a slight end percussive motion, but although fairly good results are obtained from it there is a very great difficulty in making the belts sufficiently durable.

As to the amount which may be treated on this simple machine, it is not easy to fix the exact quantity, but in Spain it is found that with one such machine a slight return pays the costs; a boy at 10*d.* per day being all the labour required, while, from two such appliances, from 5 to 6 tons of ore per month were obtained, containing 45 per cent. Pb., and at a cost of 10*s.* per ton. Before sale, however, this mineral was further enriched in a dolly, or tossing tub (see fig. 201), up to 70 per cent. Pb.

The following are the general dimensions of this machine, and the approximate amount of work which it will accomplish when treating lead slimes:—

The length of the table is 16 ft., and its width 6 ft. It is set on an inclination of 9 in. in its length, the rule being that the richer the stuff the greater the inclination. The speed of the cloth is 3 revolutions per minute, and the number of blows 75 per minute, the length of the stroke being $1\frac{1}{4}$ to $1\frac{1}{2}$ in. Under these conditions the cloth will treat about 200 cubic ft. of slimes per 24 hours, containing 4 per cent. of lead. The amount of concentrates obtained is 80 cubic ft., enriched up to 10 per cent. by one passage over the table, and the quantity of water required was 12 gallons per minute. With rich stuff the quantity is less.

The slimes were first put through a mixer, such as that shown in fig. 187, in which they were thinned down with the water before passing on to the cloth. The mixer made 9 revolutions per minute, and the number of holes in the trömmel as well as of those in the sieve of the stamps was 72 per square inch.

It will be observed that no attempt was made to classify the slimes before they were fed on to the cloth. This we think is a great error, and this applies also to the usual practice with regard to the Frue vanner. Perfect concentration cannot be obtained without previous classification, and the more perfectly the one is carried out the more satisfactory will be the results obtained from the other.

CHAPTER XVII.

FINE CONCENTRATION MACHINERY (continued).

The Frue Vanner—Description—Method of Working—Rules for Proper Consistency of Pulp—Price, Weight, and Capacity—The Improved Frue Vanner—Directions for Setting-up—Directions for Running.

FRUE VANNERS.—The Frue vanner, which is the modern development of the Brunton cloth, described at the end of the last chapter, is the outcome of a long series of experiments in the concentration of silver ores, carried out from 1872 to 1874 by the late Mr. W. B. Frue, assisted by Mr. W. McDermott.

Belts with various motions were tried, but in the end the superiority of one with a side shake was decided upon, owing to the close saving effected, although it seems to have been a keen competition between the machines having an end shake, with which the name of Embrey is associated (see fig. 210), and those with a side shake, called after Mr. Frue. The same firm* now manufactures both the machines, and holds the patents. In experiments on the same class of ore it has been found, when comparing side and end shake machines, that the end shake belt must either be placed at a greater inclination than a side shake or vanner belt, or more water used, or a more rapid shaking motion employed in order to give equally clean concentrations. It is, therefore, possible that under certain conditions in some mills the Embrey may prove more convenient than the Frue vanner.

The great step in advance of other concentrators made by the vanner, was the treatment of a stamp mill pulp at one cheap

* Messrs. Fraser and Chalmers, Ltd., London and Chicago.

operation, with the production of absolutely clean concentrations, and with surprisingly low loss of value. A material which in Germany would be divided into at least three classes, and treated on at least six machines, was treated at once on a single machine, and cleaner concentration produced than from a number of combined treatments.

It will be seen by reference to fig. 206 that the main feature of this machine is an endless inclined rubber belt, supported by rollers so as to form a plane inclined rubber surface, 4 ft. wide, 12 ft. long, and bounded on the sides by rubber flanges. The belt travels up the incline, and round a lower drum, which dips into a water tank where the mineral is collected. In addition to the travel of the belt, the latter receives a steady shaking, or



FIG. 206.—THE FRUE VANNER.

settling motion from a crank shaft along one side, the shake being at right angles to inclination and travel of belt. The ore is fed on in a stream of water about 3 ft. from head of belt, and flows slowly down the incline, subjected to the steady shaking motion, which deposits the mineral on the belt. At the head of the belt is a row of water jets.

The slow upward travel of belt brings up the deposited mineral, and the water jets wash back the lighter sand, letting only the heavy mineral pass, and deposit in the water tank below. The endless belt has long been known, and has been described on page 317, under the name of the Brunton cloth, but the shaking motion and rubber belt used in the Vanner makes an entirely different machine, enabling a separation to be made more perfect than

with any other machine, owing to the small inclination of belt necessary (from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. to foot), and very much less water than was ever before possible. The capacity of the machine is from 5 to 10 tons, according to ore treated. With very fine ore containing rich mineral, large capacity and close work are utterly incompatible. The quantity of rock treated will depend upon several circumstances. If the ore be of the very finest slimes, of course, not so much can be treated as if some of the material be coarser. If a good separation be required, the machine should not be crowded. When the ore is stamped and screened through a screen, having 50 holes to the linear inch, from 4 to 6 tons can be well separated; if the ore is a little coarser from 6 to 10 tons can be calculated upon. For running a single machine the power necessary is $\frac{1}{4}$ horse-power, while one man can attend to 16 machines without difficulty, as the only work necessary, once they have been adjusted, is to oil them and keep them clean about the working parts, regulate the water and scrape out the concentrated mineral occasionally from the water tank. When 6 machines are used the cost of treating sand, when it is ready to flow on to the machine, is estimated at less than 10¢.

When the speed of the machines is continually varying as well as the quantity of ore delivered, the above conditions do not apply, as it is essentially necessary that the speed and feed be absolutely regular and unvarying. To illustrate this very simply, watch a man tending one vanner in a mill where engine speed or water supply is irregular. Every change of speed of engine or volume of water needs a corresponding change of machine, either in water or belt travel. Next step into a mill, as several may be seen in California, with 16 vanners running like a single piece of clockwork, and one man keeping a general eye over them while handling the concentrations produced. The two cases answer all objections as to complication and difficulty of adjustment: in the first, one man is driven wild watching a single machine; in the second case, one man has an easy job looking at 16 machines, which are treating 80 to 100 tons of ore every day.

The following description together with the drawings will give an accurate idea of the construction of these machines:—

A A are the main rollers that carry the belt and form the ends

of the table. Each roller is 50 in. long and 13 in. in diameter ;

FIG. 207.—PLAN OF THE FRUE VANNER.

made of sheet iron, galvanised, and is light and strong. The

bolts which fasten the boxes of A A to the ends of F, also fasten to F the upper supports which rest on uprights, N, etc. B and C are of the same diameter, and are made in the same way as A A. The roller part of C is shorter than that of A A and B, and also has rounded edges, the upper surface of the belt with its flanges passing over it. The belt E passes through water underneath B, depositing its concentrations in the box, No. 4; and then passing out of the water the belt E passes over C, the tightener roller. B and C are hung to the shaking frame, F, by hangers, P P, which swing on the bolts fastening them to F. By means of the hand screws B and C can be adjusted on either side, thus tightening and also controlling the belt.

The boxes holding A A in place have slots and adjusting screws, so that by moving them out or in A A can be made to create a very strong influence on the belt, E; and as E sometimes travels too much towards one side, this tendency can be stopped most quickly by lengthening or shortening on one end or the other of A A; remembering that the belt always travels to the loosened side. The swinging of B or C also controls the belt.

C C are bolts and washers to take up end play of rollers, A A; these bolts pass through holes in the gudgeons of A A.

D D, etc., are the small galvanised iron rollers, and their support causes the belt, E, to form the surface of the evenly inclined plane table. This moving and shaking table has a frame, F, of ash, bolted together, and with A A as its extremities. This frame is braced by five cross pieces. The bolts holding together the frame pass through the sides close to the cross pieces; the cross pieces are parallel with A A and D D, etc., and their position can be understood by the three flat spring connections, R, O, etc., which are bolted to three of them, one to each, underneath the frame.

The belt, E, is 4 ft. wide, $27\frac{1}{2}$ ft. in entire length; being an endless belt of rubber with raised sides.

G G is the stationary frame. This is bound together by three cross timbers, which are extended on one side to support the crank shaft, H.

G G supports the whole machine, and the grade or inclination of the table is given by elevating or depressing the lower end of

G G. This is accomplished by means of wedges; for this frame rests on uprights, Nos. 3 3, fastened to two sills, which form the foundation of the machines in the mill.

F is supported on G G by uprights, N, etc.; four on each side. These uprights are of flat wrought iron, with cast-iron bearings above and below; each middle bearing on F has one bolt hole, and there are two of them on each side. The end ones have two bolt holes, and there are four of them, two on each side. These bolts pass through the frame, F, and also hold to the frame the bearings of A A, which work in a slot. The bearings of A, the upper or head roller, are higher than those of A, the foot roller—*i.e.*, A is a trifle higher than the regular plane of the table, and the first small roller, D, should be raised a trifle.

The shape of the lower or bottom bearings of the uprights, N,

etc., can be understood by examining *b*, as shown in the end elevation, and partly in the elevation. This lower bearing, *b*, extends across *G*, underneath, and is supported by a bolt passing through *G*. A lug on the upper side and on the outside end of *b* rests on *G*; and *b* hangs on the head of the bolt, and is kept stationary by the weight of *N* and its load. By striking with a hammer the face of *b* shown in the elevation, *b* is moved, changing the position of the lower bearing, and thus making *N* more or less vertical. By thus moving the lower supports of *N*, etc., the sand corners on the belt hereafter explained are regulated.

The cross timbers binding together *G G* and resting on them, are extended on one side, and on these extensions rests with its connections the main or crank shaft, *H*. This crank shaft has its bearings, *x, x, x*, on which are brass cups for lubricating compound; the cranks are $\frac{1}{2}$ in. out of centre, thus giving 1 in. throw.

I is the driving pulley that forms with its belt the entire connection with the power.

J is a cone pulley on the crank shaft, *H*. By shifting the small leather belt connecting *J* and *w*, the uphill travel of the main belt, *E*, is increased or diminished at will. The small belt connects to *J* the flanged pulley, *w*, which is on the small shaft, *K*, and by means of the handwheel can be shifted on *K* and held in place. The bearings of *K* are fastened to *Y*. *Y* is a cast-iron shell protecting the worm, *Z*, and the worm gear, *L*; *Y* turns on a bearing bolted to the outside of *G*, and thus becomes a fulcrum for *w* and *K*. The object gained by this is that the weight of *w* and *K* (from *Y*) hangs on the small leather belt, preventing slipping or wear, at the same time making it positive.

a is a screw used to relieve the small belt from the weight of *K* and *w*, taking all the strain off the small belt, and thus stopping the uphill travel instantly when desired.

m is a hand screw by means of which the pulley can be moved, adjusting the small belt on the cone, *J*, thus regulating the uphill travel.

K is the worm shaft and terminates in a worm, *Z*, which connects with a worm gear, *L*. *L* travels in a bearing bolted to the

outside of *G*. *z* and *L* are protected from dirt by the shell of cast iron, *y*, enveloping both.

The short shaft which *L* revolves, terminates in an arm, *s*, which drives a flat steel spring, *m* (which is a section of a circle), connected with the gudgeon of *A*.

N, etc., are the upright supports of the shaking table, *F*, carrying the belt, *E*.

R, etc., are three flat steel spring connections bolted underneath the cross pieces of *F*, and attached to the cranks of the shaft, *H*, by brass boxes, *O*, etc., on which are cups for lubricating compound. These springs give the quick lateral motion—about 200 a minute.

FIG. 209.—END ELEVATION OF FRUE VANNER.

Q Q are two flywheels.

v v are two rods passing from the middle cross timber to the lugs for same at the foot of *F*. The cast-iron washers on the bolts of the cross timbers have lugs cast on them. *v v* pass through these lugs, and at each end are nuts on each side of the lugs. Thus, *v v* prevent the movable frame, *N*, from sliding either up or down, and by them *F* is squared.

No. 2 is the clear water distributor, and is a wooden trough which is supplied with water by a pipe, and the water discharges on the belt in drops by grooves 3 in. apart. Another form generally used for No. 2 is an iron trough with brass spout $1\frac{1}{2}$ in. apart, so that by blocking every other hole, water jets can be made 3 in. apart.

No. 1 is the ore spreader, which moves with F, and delivers the ore and water evenly on the belt.

n is a copper *well* that fits in (and shakes with) the ore spreader at the place shown in the drawing. This is used in concentrating gold ores, for saving *amalgam* and *quicksilver* escaping from the silvered plates above, and can be taken out and emptied at any time. Into this well falls all the pulp from the battery. Its ends are lower than the wooden blocks of the spreader, so that the pulp passes over the ends of the well and is evenly distributed.

For some gold ores it is desirable to use on the ore spreader a silvered copper plate the size of the spreader, and when this is used the wooden blocks of the spreader are fastened to a movable frame on top, so that they can be removed when the plate is cleaned up once or twice a month. (This amalgam saver is charged extra for.)

Nos. 5, 5 are the cocks to regulate the water from the pipes, Nos. 6, 6.

Nos. 3, 3 are upright posts, which are firmly fastened into two sills. These posts are cut down on the inside to make square shoulders, on which G G rests.

No. 4 is the concentration box, in which the water is kept at the right height to wash the surface of the belt as it passes through.

Nos. 3 and 4 are generally made at the mill; but can be supplied by the makers at a cost of about \$18.

The overflow from No. 4 contains finely-divided sulphurets in suspension; to settle them the water passes through boxes Nos. 7, 7, 7.

No. 8 is a section of the launder to carry off the tailings.

No. 9 is a box into which the concentrations fall when scraped out of No. 4.

Nos. 7, 8, and 9 are made at the mill.

Nos. 10 and 11 show arrangement of countershaft with tight and loose pulleys for driving machine, but should be higher above machine than shown in drawing.

Method of working.—The ore is fed with water on the belt, E, by means of the spreader, No. 1. Thus the feed is spread uniformly across the belt. A small amount of clear water is

distributed by No. 2, which is a wooden trough in which is a pipe, No. 6, or an iron trough with brass spouts.

Both No. 6 and No. 2 can be supported from the upper cross-timber of G G.

A depth of $\frac{3}{8}$ to $\frac{1}{2}$ in. of sand and water is constantly kept on the table.

The main shaft, H, should be given the proper speed for each kind of ore. We seldom find the ore in one district just the same as in other places, but when the machine is adjusted to the ore, and the best speed is established, this motion should be kept uniform. The best motion will probably be found between 180 and 200 revolutions of the crank shaft per minute, with 1 in. throw.

The uphill travel or progressive motion varies from 2 ft. to 12 ft. a minute, according to the ore ; and the grade or inclination of the table is from 3 in. to 6 in. in 12 ft., varying with the ore. The inclination can be changed at will by wedges at the foot of the machine, these wedges being under the lower end of G G, and resting on shoulders of uprights, from the main timber of the mill.

The motion, the water used, the grade, and the uphill travel should be regulated for every ore individually, but, once established, no further trouble will be experienced in the manipulation.

In treating ore directly from the stamp, too much water may possibly be used by the stamps for proper treatment of the sand by the machine. In such a case there should be a box between the stamps and the concentrator, from which the sand with the proper amount of water can be drawn from the bottom ; and the superfluous water will pass away from the top of the box ; but as mineral will also pass away with this water, there should be settling tanks for it, and the settlings can be worked from time to time as they accumulate.

The main body of the belt suffers hardly any wear at all, since it merely moves its own weight slowly around the freely revolving rollers ; and the life of the belt is lengthened by this *precaution* : viz., to keep it clean from sand at every point except the working surface ; thus sand cannot come between the belt and the various rollers. All the bearings should also be kept clean ; a

machine cleanly worked gives better results, and less wear and tear, and requires less power to drive than a machine allowed to be covered with dirt. With a clean machine the wear of bearings is very slight.

The concentration box, No. 4, which is kept full of water, and through which E passes, may be of any size or depth desired. Though not indispensable, it is best to have a few jets of water playing above and underneath on the belt as it emerges from the water in No. 4, so as to wash back any fine material adhering to the belt, and as such a method will cause an overflow in No. 4, the waste water, being full of finely-divided mineral, should be settled carefully in the boxes, Nos. 7, 7, 7. Every few hours the concentrations may be scraped out with a hoe into the box, No. 9, and if this box be on wheels, it can be readily run on a track to the place where the concentrations are stored.

Rules for Proper Consistency of Pulp.—That there is used the proper quantity of water with the pulp from the stamps is very important, and this should be carefully regulated. There should be formed on each side of the belt a *slight corner of sand*—i.e., there should be on each side sand, with less water in it than there is in the balance of the pulp on the belt. If there is not a slight sand corner, the corner will be sloppy, and there will be a *loss*. *Sloppy corners* are caused by using *too much* water with the pulp from the stamps passing on No. 1.

Frequently, on the other hand, there may not be *enough* water with the pulp from the stamps, and the result will be *too heavy* sand corners. The remedy for this is to use *more* water in the pulp coming on No. 1.

As regards the proper amount of water to be used in the water spreader, No. 2, use just enough (no more) to keep covered the *field* between No. 1 and No. 2, so that no points (or fingers) of sand shall show on the surface. The whole width of the belt between the water spreader and ore spreader should be kept quite wet. If dry streaks or points occur, and water, as a consequence, runs in streaks, at the junction of the wet and dry channels mineral will be picked up and “floated” away on the surface of the water; this “floating” of mineral is caused by its dryness, not by its lightness: it has been coated with a film of air.

The proper amount of water with the pulp on No. 1, and the proper amount of water in No. 2 being fixed, the carrying over of the clean concentrations past the jets of No. 2 should be accomplished and regulated by the uphill travel only.

Frequently the sand and water on the belt will be distributed *unevenly*, the sand working to one side of the belt, and making a heavy, broad corner, while the other is sloppy. To control and remedy this, see first that there is no jar about the machine; that there are no loosely-working parts, that everything is working noiselessly, and that all the parts are in line. If, then, there is not an exact balance of the pulp on the belt, the heavy sand corner forms on one side or the other. To adjust the *load* and keep the sand evenly distributed on the belt, the lower bearings, *b*, of all the uprights, *N*, on one side of the machine, are moved forwards or backwards by slight blows of the hammer. The change of position from the vertical of *N*, etc., thus occasioned affects the pulp on the belt; and by changing the position of *b*, etc., on one side or the other, the right balance or equilibrium will be obtained, and the sand and water (or pulp) will be uniformly distributed across the belt; e.g., if the heavy sand corner is on the shaft side move the bottom bearings, *b*, etc., on the opposite side, *out*.

Again, the sand corner can be partly controlled by bending the end of the driving spring that is fastened in the collar towards the side having thickest sands.

The same effect, and even more positive, is produced by moving the crank shaft (and with it the table) the same way as the end of the driving spring is bent.

The underneath rolls have also some effect on the corners, by swinging one end of each either towards one another or in the opposite direction.

The water in the concentration box is constantly agitated by the motion of the belt, and consequently the water escaping from this box carries in suspension quite an amount of very finely-divided sulphurets of high assay value. To save these there should be used settling boxes, Nos. 7, 7, 7, which can be cleaned out once a month, and a product obtained which will add materially to the value obtained from the ore. Two men understanding the machine can put it together in a few hours.

Regarding the bearings of A A—those of the head roller are *higher* than those of the foot roller. The head roller is a little higher than the regular plane of the table, and it is also advisable to raise the small roller and its bearing next to it, by a piece of wood. This additional elevation enables us to use less water at No. 2 than would be otherwise necessary.

The lower edge of No. 1 should be within an inch of the surface of the belt, E.

Price, Weight, Water, and Capacity.—The price of each machine is \$575, at the works in Chicago or on vessel in New York, but in this price are not included the parts represented by the Nos. 3 and 4. These parts are generally built at the mill, but will be furnished by the makers if so ordered, at cost price, \$18; and their weight, ready for shipment, will be about 500 lb. The machine proper, boxed ready for shipment, weighs 2240 lb., and no part weighs over 160 lb.

For one machine from 1 to $1\frac{1}{2}$ gallon of clear water per minute is used at the head, and from $1\frac{1}{2}$ to 3 gallons per minute with the pulp.

The boiler for a 5-stamp mill, with two concentrators, calls for one gallon a minute; hence, in places where water is extremely scarce, two gallons a minute *can* supply five stamps, two Frue ore concentrators, and the boiler by settling and pumping back.

As regards the capacity of the Frue ore concentrator, late practice demonstrates that about 6 tons per 24 hours, passing about a 40-mesh screen, is as much as it is advisable to treat. If a battery of five stamps does its duty, the quantity crushed is largely in excess of 6 tons; for this reason the best practice is to put 2 Frue vanners to 5 stamps, if the stamps are heavy and the sulphurets are high grade and difficult to save. Where pulp from 5 stamps is fed to two machines, the pulp is divided, one-half passing on each. The machines are generally placed in a double row on the same level, head to head, so that the attendant overlooks both rows in walking between; the concentrator floor should be so far below the level of the battery as to allow the feed launder to be above the head of the attendant.

In many cases 3 Frue vanners to 10 stamps will yield entirely satisfactory work, and where the gangue is light, or the stamps

not heavy, one is sufficient to treat all the ore crushed by 5 stamps. In one case in California 8 vanners are treating all the ore from 40 stamps, the tailings assay nothing, and the entire cost of milling is under \$1 per ton.

A great feature of the vanner is that no sizing of the pulp or slimes is necessary; they pass direct from the stamps on to the copper plates if these are used, and thence on to the vanner.

In some cases it is desired, either as a security against loss from careless work at the battery or in the treatment of special gold ores, to save amalgam as well as sulphurets on the concentrator. For this purpose a special device is needed, and very simply applied either to vanner or Embrey machines. An amalgamated copper plate, 3 ft. to 8 ft. long, is attached to shaking frame, and across it, at bottom and top, low cleats are nailed, forming riffles. This device is found the most effective possible for catching amalgam; hard amalgam is caught in the riffles and by the shaking motion rolled into small pellets, which are collected at intervals. The copper plate itself by the shaking motion becomes an excellent addition to the amalgamating apron at battery, and at several mills valuable returns are obtained in this way. We may mention one small mill in New Mexico, where from \$150 to \$200 per day is cleaned up from these shaking feed coppers on vanners. The amalgam saving device is supplied with either side or end shake machine if desired, in place of ordinary pulp distributors.

The vanner can be used for the concentration of almost any ore, the only point of great importance being that there is a fair difference between the specific gravity of the mineral to be saved and that of the waste matter with it. The following minerals have been worked upon with excellent results:—Iron and copper pyrites, arsenical iron pyrites, zinc blende, galena, tin stone, cinnabar, native silver, carbonates of lead and copper, tellurides of gold and silver; and in the case of “tailings” from amalgamating mills, “floured” quicksilver and slimes from settling tanks have been experimented upon, and made to yield the impalpable mineral they contain.

THE IMPROVED FRUE VANNER. — In the vanner which has just been described the belt was quite smooth, and, indeed, this

form of belt is, perhaps, the best for saving fine slimes, as compared with one with a roughened surface. It has been demonstrated, however, that a certain form of belt surface has an important effect, allowing the use of a steeper inclination and more water, and as a consequence greatly increasing the capacity. Indeed, it is stated that after a comparative trial of several months between the two types of machines, the one with a special belt was able to treat as much material as two with a smooth one, to which must be added the saving in first cost, erection, space, power, and surveillance.

The form of the machine itself is not altered, with the exception of some slight modification; the essential difference is in the belt itself, which is both heavier and more costly,—the price of the new type of machine being £165 or \$825, as compared with £112 or \$575.

There are, however, certain differences in the manner of erecting and running the new machine, which may be summarised as follows :—

Directions for Setting Up.—Rollers.—As the belt is heavier than the old style belt, and carries a heavier load just below the pulp spreader, a few extra small supporting rollers are introduced on the shaking frame.

Inclination.—In the old style machine there is an increased inclination to the upper end of the belt as compared with the lower part. This extra grade at the head is still further increased by about $\frac{1}{4}$ in., which is provided for by the relative heights of roller bearings in the new machine.

Water Distributer.—This is practically the same as that in the regular style of the machine. The jets should be spaced, however, to correspond with the class of pulp being run. For the average pulp from a stamp mill the jets should be about $2\frac{1}{4}$ in. apart. The distributer is placed from 1 in. to 2 in. higher up towards the head of the belt than in the old machines, owing to increased inclination here. The distributer is also raised somewhat higher above the belt so as to give a drop of about $1\frac{3}{8}$ in. from the spouts to the belt surface, giving in this way a little greater efficiency from increased force of impact.

Pulp Distributer.—This should be somewhat flat and as close

to the belt as possible, so as to make a gentle delivery without force on to the belt.

Speed.—The number of revolutions of the crank shaft may vary from 180 to 210 according to the class of pulp being worked. For ordinary stamp mill crushing, from 195 to 205 should be the limit in either direction.

In arranging pulleys, calculation should be made from the minimum speed when the power is variable, so that in no case will the machine run less than 194, and any variations will be by increase not decrease of speed—work being less affected by the former than the latter.

The forward motion of belt will depend on inclination and ore somewhat, but should usually be about 29 in. to 36 in. per minute.

Directions for Running.—The improved vanner, besides being used to take the pulp direct from the stamps on all ordinary milling ores, can be used with special advantage on all concentrating ores, where the pulp is sized. It will handle all sizes from No. 10 mesh to the finest slimes, doing the best of work and having a large capacity, replacing fine jigs, concentrators, and slime tables.

It is also especially adapted to ores carrying a large percentage of valuable mineral.

When the belt is to be used for concentrating sized pulp or very heavily mineralised pulp, special directions should be obtained for setting up and running. For all ordinary work the following directions will be adhered to.

General.—The necessity for firm setting up, accurate adjustment, regularity in speed and water and pulp supply, as well as the importance of *perfect cleanliness*, applies equally to the new as the old machines, and full directions are published on the subject.

The special directions to be noted in adjustment of the improved machine are as follows:—

Described generally, it can be said that the new machine requires more wash water and inclination, and a less bed of pulp than the old machine.

Inclination.—An average inclination of the machine should be from 3 in. to 5 in. in 12 ft. This may be increased to 10 in. in the case of coarse sized pulp, or diminished to $\frac{1}{2}$ in. in the case of

absolute slimes. As a rule, the machine should first be set a trifle steep; and then, with a normal speed, of say 200 shakes, and a good flow of wash water from the water distributor, the inclination should be decreased little by little till a slight bed of pulp is formed on the belt, so that by putting the hand into the flowing pulp the grains of sand can just be felt slowly rolling down the belt, and can be picked up between the fingers. This bed of pulp will be more apparent just below the ore distributor, but lower down the belt should be less. Any indication of stickiness or of a heavy bed settling in the depressions means poor work.

Battery Water should usually be as light as is consistent with good work on the copper plates where these are used before the concentrator; and in this connection it is worth while stating that full-width coppers should have an inclination of $1\frac{3}{4}$ in. to 2 in. to the foot. If used too flat, they need too much water to clear them of sulphides. The pulp should fall gently on to the belt, and be well distributed across it. The distributor should be as close down to the top of the belt flanges as possible, and be placed as flat as practicable for a free flow of the pulp over it.

Wash Water.—More of this is required than on the plain belt, but of course not in excess of what is required to make clean sulphurets. The quantity varies from $1\frac{1}{2}$ to 3 gallons per minute. Ordinarily the lower edge of water distributor should be fully $1\frac{1}{2}$ in. above belt surface, so as to give this extra force to the falling streams; but on fine crushing or very slimy ores, the jets should be closer together, and the distributor set nearer the belt.

Forward Motion of the belt should be kept *slow* (a normal speed is 32 in. per minute), and is less used as a means of adjustment than with the plain belt; the travel usually being only increased if percentage of sulphurets is unusually large, and a large quantity of pulp being treated, and in this case the belt will probably require more grade and a faster shake.

Having the machine now in good order, running at say 200 revolutions, battery water normal, and the belt at such an inclination that a light bed of pulp is beginning to form, the following points are to be observed:—

If the concentrates are coming over clean, the inclination of

belt may be decreased a little up to the point where such a decrease involves impure concentrates ; but, as a rule, a light bed with clean concentrates means the best general work of the machine, and small value in the tailings. In case of bed getting heavy, or concentrates carrying too much sand, a slight increase of speed will remedy both defects. Variations in character of ore, and size of crushing, involve slight changes in the minimum speed to be used ; but when this is once determined the machine will run regularly, giving clean sulphurets, and requiring only attention to wash water and oiling.

The wash water distributor must be kept clean, so that the streams remain constant.

If the concentrates carry sand, and the bed of pulp is heavy, while the speed is normal or fast an increased inclination of belt is necessary.

If the concentrates carry sand, and bed of pulp on belt is light, an increase of speed, with perhaps decrease in inclination, is desirable.

Use wash water more liberally than with the plain belt ; but too great an excess will bank up sulphurets and sand below distributor, and the two will go over together. In this latter case increase speed and decrease wash water.

Keep the bed light rather than thick or pasty, and refrain from changes in speed or forward motion of the belt, trusting almost entirely to speed of shake, inclination, and wash water to regulate the work of machine.

As a rule, a very slimy pulp requires less inclination, a slower shake, and more battery water than a cleaner and more sandy pulp.

The General Principles on which the new belt must be regulated are as follows :—

1. The pulp and water flowing down the belt is prevented from actual settling by the shaking motion. This motion or agitation must be such as to just allow the pulp to settle, but not to pack or stick ; and this consistency allows the particles of mineral and coarser sand to sink into the depressions of the belt surface.

2. The inclination of the belt regulates the speed of the down flow of the water. This last should be just such as not to disturb the settling due to the shaking motion, but just enough to keep

the lighter particles of sand flowing slowly down the belt from one ridge to another, keeping this flow up to the quantity of pulp coming on. In this way, by using a shallow bed or stream of pulp, the separation of mineral is a continuous one, and over a series of *rising surfaces* which only permit the lighter particles to go over them. For this reason a deep bed or a sticky, thick pasty bed does not permit of this method of separation, and the depressions in the belt become overcharged with coarser sand, and soon spoil the concentrates by carrying the load past the water jets. It follows that to get the benefit of the new belt we must have a *quick shake*, a *shallow bed of pulp*, and a *fair grade*.

3. At a normal speed of belt travel—say 32 in. per minute—the new belt will carry up, without overloading the depressions, at least 1000 lb. of sulphides in 24 hours. A faster speed is therefore in few cases necessary. An increase in speed of belt travel should only be resorted to when an accumulation of sulphurets is noticed on the belt below the ore spreader, and then only a *very slight* increase is sufficient; and, moreover, such accumulation of sulphurets is usually due to machine being run too slow or too flat.

A good general plan of starting the belt on a new ore is as follows:—

Set the frame with a fall of 4 in. on the 12 ft. ($\frac{1}{3}$ in. to foot), give a speed of 200 revolutions per minute to crank shaft. Give good fair streams of water to water jets of water distributor. See that stamp battery is using no more water than necessary for copper plates; allow the machine to run 15 or 20 minutes; the sulphurets come over at once. The bed of pulp is then examined by the hand, just behind the ore spreader, and should be of such a consistency that the heavier grains of sand can be felt under the fingers slowly rolling down the belt, and by closing the fingers together some of the grains can be caught between them. If a sticky bed is forming on the belt, increase the grade a little, and in case the ore slimes badly, an increase in battery water may be necessary; but if there is no bed only a thin and rapid stream of water and pulp, the grade is flattened till the right consistency of pulp is obtained. Of the two extremes, insufficient bed is preferable to too heavy and sticky a bed.

Having the pulp right, the sulphides next claim attention. The "field" of sulphides should be thin, and the sand covering should not extend up to the water distributor. This is arranged by regulating the water jets. If gangue is heavy and works up too far under the water distributor, increased speed of shake is necessary, and this may allow of a slight flattening of grade.

The belt must be set true without jar in running. No sand corners form as with the plain belt, but they are indicated and must not be "sloppy." If speed of mill slows down, forward motion of belt must be stopped at once or sand will come over and spoil the collected sulphides. If mill is stopped, the belt should be cleaned off to prevent the sulphides *rusting* into the depressions. If this last does occur clean well with a soft bristle brush, moving it from side to side.

CHAPTER XVIII.

FINE CONCENTRATION MACHINERY (continued).

The Embrey Concentrator—Description—Operation of the Machine—Directions for Working—The Bilharz Slime Table—Losses in Concentration—Tin Dressing in Cornwall.

THE EMBREY ORE CONCENTRATOR.—The side shake which is the peculiarity of the Frue vanner is, perhaps, not altogether suited to every variety of ore, and so in the Embrey concentrator this is replaced by an end shake of from 200 to 220 per minute, which is found to be sufficient to prevent the slimes and pulp from settling on the surface of the belt before the separation between the rich mineral and the steriles is effected.

The machine consists of an endless belt, E, fig. 210, with flanges on its edges, supported on rollers in an inclined position, and having two motions, one a slow revolving one up the incline, the other a vibratory shaking motion imparted by a crank or eccentric shaft to the frame carrying the supporting rollers.

By reference to the drawings, figs. 210, 211, 212, the construction and action of the machine can be readily understood. G G is the main frame, consisting of two sides, made up as shown of cap, sill, posts, and two braces, all bolted strongly together. These two side frames are joined together by cross sills and bolts at the bottom, and long bolts with collar, shoulders, inside at the top, as indicated in the drawing.

The framework, when erected, makes a stiff support for the whole machine, and can be set on an ordinary floor, and blocked up at the front end if desired, for variations in the inclination of the belt when necessary.

The frame should be placed in such a position that the head or upper end of the machine where the water distributor is, stands in a good light and with a clear space in front of at least 4 ft., or, better still, 5 ft. if possible. It is at the head of the machine that the concentrations are collected, so that the importance of light and space can be understood. At the lower end the only clear space required is that sufficient for the passing round of the machine for oiling, etc., and 2 ft. is ample for this.

Within the main frame a light shaking frame, F, is supported, on which the belt is carried. This frame, F, consists of two sides of wood with cross braces and bolts, and carries at each end a set of bearings in which the end rollers, A A', revolve. Between these end rollers a number of small galvanised iron rollers, D D, are carried in bearings on the shaking frame, and with the end



FIG. 311.—LONGITUDINAL SECTION OF THE EMBREY CONCENTRATOR.

rollers form an inclined plane on which the upper or working surface of the belt, E, is supported. The belt, E, is made of rubber with canvas filling, has soft flexible rubber flanges around its edges to prevent the overflow of water from its surface, is $27\frac{1}{2}$ ft. in length and 4 ft. in width. This belt is a special article of manufacture, which has taken several years to perfect. Any defects in its construction or impurity in material used involves a rapid wear of the belt, and the cost of renewal is high. Experience has shown that perfect belts will last with constant service from three to six years if properly cared for. The shaking frame is supported on six legs or toggles, N N, which stand in adjustable stirrups, $\delta \delta$, hanging on the main frame, and which are used some-

times for slight changes in inclination of frame or levelling of the belt across. The shaking frame, F, is connected by short connecting rods, R R, attached to the lower roller bearings, to two eccentrics having about $\frac{3}{4}$ in. motion, and fixed on driving shaft, H. This driving shaft is fitted with tight and loose pulleys, I, which can be driven by a 3-in. belt from broad-faced pulley on any convenient shaft in the mill, or from a special countershaft put up above the machine. There are two small flywheels, Q Q, on the driving shaft, and also a cone pulley, J¹, which is connected by narrow leather belt to a corresponding cone pulley, J, on the shaft below. The speed of this lower shaft can be regulated as shown by the belt shifter, m², actuated through the small bevel-gear and screw, m¹, by means of the hand wheel and rod, m, at the head of the machine. The motion of this lower shaft is communicated by bevel gear to the worm, Z, which in turn gives a slow revolution to the worm gear, L, on shaft of roller, B¹, around which the endless apron plies. The effect of the revolution of worm gear, L, with its attached roller, B¹, is to give a slow travel upward of the rubber apron, E, on which the concentration is effected, while at the same time the eccentrics on the driving shaft give the upper surface of the belt, through its supporting frame, a rapid but steady vibratory or shaking motion. The belt has therefore two motions: a slow forward motion, and a rapid vibratory motion, the effects of which will be explained later.

The endless travelling belt is kept in position below by the three fixed rollers, B, C, B¹, of which C serves as a tightener, and in part as a regulator of the travel of the broad belt in keeping it straight on the shaking frame above. This latter object is also served at need by the adjustable bearings of the rollers, A¹ B, which, by tightening on one or the other side of belt, causes it to travel to one or the other side of its course, and so admits of neutralising any tendency to run off the supporting rollers. The lower front roller, B, dips into a tank of water, 4, so that the belt in passing around it is submerged for a short time, so as to wash off any adhering concentrations which collect in the tank, 4.

On the upper side of the main frame, G, are four short cast-iron

standards, with projections inside which serve as guides to the sides of the shaking frame, so that its motion is simply in the line of its length without any side play. One of these standards, a^1 , is higher than the other three, and serves a double purpose: its upper part being used as a support for a bell crank, k , which is attached by a strap connection, c , on the inside to the shaking frame, F . The outer arm of this bell crank, k , is attached to one of two clamps, r , on the movable water pipe, 2 , which stands on two spring legs, $d\ d$, bolted below in sockets, $f\ f$. This water pipe, 2 , is fitted with a number of small jet cocks on its under side, and at one end is connected with water supply by a flexible hose coupling to allow of its motion by the bell crank, k . The effect of the spring leg support and bell crank attachment to the shaking frame, is to give the pipe, 2 , a rapid shaking motion across the width of the belt, E , and coincident with the longitudinal shake given by the eccentrics, $o\ o$.

No. 1 is the ore distributor which receives the material to be concentrated, and spreads the same over the width of the belt. It is constructed as follows: The body of the distributor is a low open frame or box, with bottom, back, and two sides, but open in the front. At the front end there is a turned-up lip of sheet iron, h , with a number of holes punched along its bottom. c is a board with strips of wood attached on its lower side, arranged as shown by dotted lines in the plan. These cleats or buttons are arranged so as to break up the current of water and pulp flowing around them, spreading the same evenly over the whole width of the distributor. At the back end of the spreader board, g , there is an opening into which is placed a small copper tank, j , which receives the flow from any launder or pipe of the pulp to be treated, and serves to retain any quicksilver or amalgam in the case of gold milling. In working gold ores, an electro silver-plated copper plate, i , is placed on the distributor, and under the spreader board, g . This plate with the copper tank, j , constitutes what is called an amalgam saver, and can be added to the machine at an additional cost of \$30, when desired.

Operation of the Machine.—The arrangement of supporting stirrups and shaking frame, F , gives the latter and the belt it supports a slight incline when the main frame is placed level on

the ground. This inclination can be readily increased or diminished by blocking up one or the other end of the main frame, G. This blocking is best effected at the upper end, as not interfering then with the driving belt to the pulley at the lower end. Supposing the inclination of the belt to be adjusted, the operation of the concentrator is as follows:—

The crushed ore—not coarser than 30-mesh and preferably 40-



FIG. 212.—FRONT END ELEVATION OF THE EMBREY CONCENTRATOR.

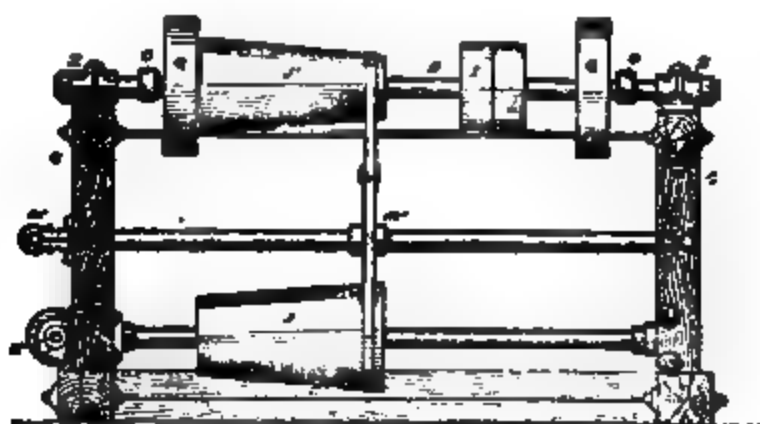


FIG. 212 A.—BACK END OF EMBREY CONCENTRATOR, SHOWING DRIVING GEAR.

mesh size—in a small stream of water falls on to the distributor, 1, thence is spread evenly over the full width of the belt, E, and flows gently down the incline to the lower end of the machine. The belt is subjected to a steady rapid shaking motion in the direction of its length, by the revolution of crank shaft, H, and at the same time it has a slow forward travel up the incline, communicated by the cone pulleys, J J¹, and worm gear, L. The

effect of this forward travel is to carry up all heavy particles of ore which settle on to the belt, in the passage of pulp down its surface, assisted by the shaking motion. This shaking motion, by keeping all the pulp in gentle agitation, prevents the sand from packing on the belt in a mass—as it would do otherwise on so slight an incline with the small quantity of water used—and causes the heavier mineral particles to settle down to the belt, while the lighter waste rock is kept suspended in the flowing water, and passes off at the lower end as waste or tailings. The forward travel of the belt carries up to the water distributor, 2, all the heavy mineral particles, and here by the action of the many small jets of clean water falling on the belt, a final separation of the clean mineral from any adhering rock particles is effected. The mineral is carried past the jets of water by the revolving belt surface to which it adheres, and is deposited in the concentration tank, 4, where it is washed off by the passage of the belt through the water, as shown in the drawing. At intervals the concentrations are scraped out of the tank, 4. The lighter rock or waste and muddy water, constituting the tailings, flow off the lower end of the belt into a suitable trough, which carries them out of the building.

Directions for Working.—The machine, when set up square, firm, and with all bearings in proper condition, should run *easily and noiselessly*. The concentration tank, 4, should have always sufficient water to properly immerse the belt as it passes around roller, B, and should be built with sloping front as shown, to facilitate the scraping out of the concentrates at intervals as they collect, to prevent accumulation and rubbing against the belt from a pile below it. The front of the tank is better with a flatter slope than shown in drawing. The main frame, G, should be firm and free from motion.

The inclination on the length of belt is usually about 3 in. Speed of crank shaft, H, 200 to 220. The lower speed is preferable if satisfactory work can be accomplished by regulation of inclination and forward speed of belt. Having a fixed inclination and speed of shake, small jets of water are opened from distributor, 2, using as little water as possible, and then the chief means of adjusting the delivery of concentrates should be by the forward

speed of belt through hand wheel, *m*. On some ores the shaking water distributor will be found a great improvement, on others the water pipe can be disconnected from the shaking frame and remain stationary. When the water distributor is in motion, less water is required to make clean concentrates than if stationary.

The material treated on the machine should not be coarser than 30 mesh—*i. e.*, should pass a wire screen of 30 holes to lineal inch. In case of coarser crushing, jigs should be used for all sizes above 30 mesh. The usual size for this class of a concentrator is 40 mesh. In regard to quantity, the machine can be calculated on from 6 to 10 tons per 24 hours, and, therefore, either one or two machines are used to each 5 stamps, according to character of ore and closeness of concentration required. If one machine only is used to 5 stamps, the belt should be placed flatter and with a faster forward motion than if the pulp be divided between two machines, owing to the large quantity of water. In case it should be necessary to settle away the pulp from an excess of water, large pointed boxes are used with continuous discharge from the bottom, and overflow of clear water from the top.

In regulating the forward motion of the belt, the steady delivery of clean mineral is the point to be aimed at. If sand is seen coming over, the forward motion is reduced; if mineral collects in quantity below the clear water jets, and spreads down the belt for some distance, it shows that discharge is not as rapid as it should be, and belt should travel faster. In the best work clean mineral should come over, and sand be seen clearly over the mineral two or three inches only below the water jets.

The quantity of clear water used is from $\frac{3}{4}$ to $1\frac{1}{2}$ gallon per minute. The quantity of water coming on with the pulp is usually from $1\frac{1}{2}$ to 3 gallons per minute.

It is of great importance to keep the concentrator absolutely clean. No splashing around of pulp must be allowed, or belt and bearings will soon be ruined. It is the care taken in keeping all parts clean, and play in joints taken up, that determines not only the life of the machine, but the character of the work done by it. *Speed should be regular*, or action cannot be automatic, and clean mineral cannot be made, and it is equally important that ore feed

and water supply should be regular. With ores producing rich mineral concentrates, a perforated water pipe should be placed under the belt just above and at the back of the concentration tank, 4, so as to wash back any mineral which might cling to the belt as it leaves the water. This arrangement necessitates an overflow from the concentration tank, which should be near the *front end*, and should discharge into a settling box with at least one partition dipping below the surface, to prevent loss of floating mineral. This settling box is easily made of 1-in. boards about 6 ft. long, 10 in. wide and 8 in. deep, and can be placed along one side of the machine on the floor, receiving the tank overflow at one end, and discharging from the other into the tailings launder at lower end of concentrator.

The concentration tank, 4, should be scraped out at intervals with a hoe into a lower box placed under the lip of the tank. In some cases a low flat car on wheels is used, and run from one machine to another, receiving the scrapings of the various tanks till full, and then taken to the drying floor.

It is well to see that the first small roller, D, at the upper end is sufficiently raised by its bearings above the frame, to just touch and support the belt, so as to prevent any flapping up and down of the latter, which would prevent good work. At the same time this roller should not be so high as to unduly raise the belt at this point from the general plane. The regulation of this roller is easily effected by loosening the screws of its bearings, and putting under the latter small strips of wood or rubber, till the proper height is secured.

To recapitulate the most important points to be observed in running the concentrator :

- (1) *Perfect regularity in feed, in speed, and in water supply.*
- (2) *Perfect cleanliness of machine.* All woodwork as well as ironwork should be gone over every day by the man in charge, and all sand, dirt, or oil drippings removed.
- (3) Proper attention to bearings, reasonable oiling, and taking up all the looseness or play. This includes, of course, watching the eccentrics to prevent play or heating.
- (4) Avoidance of excess of water at head of machine as well as with pulp.

(5) Regulation chiefly by forward motion of belt, after once adjusting inclination and water supply. If it be attempted to regulate by water at head, too much attention is required.

The shipping weight of machine is about 2800 lb. Price \$550, f. o. b., Chicago, New York, or San Francisco.

Full instructions and working drawings are sent out with both the Frue vanners and the Embrey concentrators, so that the mine manager should have no difficulty in erecting them and getting them to work efficiently.

THE BILHARZ SLIME TABLE.—One of the perfections of the Frue vanner is that it makes two classes of ore,—the rich and the sterile. With some kinds of mineral, however, this is a disad-

FIG. 213. BILHARZ AUTOMATIC PERCUSSION TABLE.

vantage, as, for instance, with an ore containing galena, blende, and quartz, when it is desired to separate and retain both the galena and the blende, and reject only the quartz. This separation could not be effected at one operation on a vanner, and either a Rittinger or a Bilharz table would have to be employed.

The working face of a Bilharz table is rectangular in form, as shown in fig. 213, and at each of the ends a roller is fixed, between which there is a fixed bed plate. The framework is hung upon two supports, which can be raised or lowered so as to give any desired inclination to the table. An endless rubber belt passes over the table and round the rollers at the end, being supported and kept quite flat by the surface of the table, across which several diagonal channels are cut, along which water is

forced and spreads over the surface of the table, thus diminishing the friction between the belt and the bed plate. It is claimed that this is a great improvement over the older method of passing the belt over rollers, as in the Frue vanner, as a more even surface is obtained, and the abrasion of the belt avoided.

One of the rolls takes the power and drives the belt ; the other can be regulated to suit the tension, etc. The travel of the belt is 0·07 metres, or say 3 in. per second, and a percussive motion of 150 blows per minute is also given to it. In the right-hand top corner of the illustration is seen the feeding box, by which the slimes enter. These are washed down in their passage across the belt by a spray of clean water supplied from the iron pipe which crosses it obliquely. The water can be regulated by a tap.

The light particles flow away at once, but the heavier are concentrated according to their gravity by means of the travel of the belt and the vibration, and are carried along until swept off into the several divisions of the trough shown at the foot of the table, whence they fall into the various cases shown beneath. The separation of the slimes is very perfect and rapid, and the machine can be applied to the handling of auriferous ores as well as to the more complicated ones.

Very little foundation is required, and very little power to drive it, and provided that the speed, feed, and water supply are regular, it needs but little attention.

But little water is necessary, and it is said that it can be pumped back and used over again. The machine weighs about 1 ton, and its price at the factory in Germany is £77.

LOSSES IN CONCENTRATION.—The conduct of the various washing processes employed in the concentration of the ores of lead, copper, zinc, and tin requires constant watching, in order to prevent losses, not only by the carrying of mineral matter away with the steriles, but also from enriching the mineral beyond the economic point, at which concentration must cease, or loss be entailed from the washing away of the silver usually associated with these ores.

A system of sampling and assay must therefore be devised, and regularly followed throughout the various machines. The first point is to get an exact idea as to the quality of the ore as

it arrives from the mine, and this can best be done by sampling the crushed ore as it passes from the first rolls or stamps to the first series of trommels, either automatically by a machine, or by hand. In the latter case one of the foremen in the mill can take a small boxful every half-hour, and put it into a case kept on purpose. From this case or box the assayer can take his sample at the end of the day.

The result obtained is given in percentage or units of metal, but care must be taken not to confound these two expressions. Let us assume that the crude ore contains 10 per cent. or 10 units of lead, or, in other words, that it will require 10 tons of the ore to yield 1 ton of lead. Now if the loss which is found in the tailings from the mill is $2\frac{1}{2}$ units, it must not be expressed as being $2\frac{1}{2}$ per cent., which would imply that only $2\frac{1}{2}$ units were lost in every 100, but distinctly as units, meaning that out of the 10 units of lead in every ton of crude ore $2\frac{1}{2}$ units, or one-fourth of that amount, was lost, which would indeed be of a very appreciable value, and point to gross carelessness or unsuitable machinery somewhere.

In calculating the quantity of a metal contained in a pile of ore, or the probable milling results to be obtained from treating a given quantity, the assay of the crude ore is the basis. Let us assume that it is desired to know what dressed mineral may be obtained from a pile of, say, 200 tons of crude ore assaying 5 per cent. Pb. The total number of units of lead in this pile would be $200 \times 5 = 1000 \div 100 = 10$ tons of metallic lead, or, if there is no loss in dressing, 20 tons of 50 per cent. ore. But there is always some loss in the milling operations, and the probability is that the tailings from the mill will contain from $\frac{3}{4}$ to 1 unit of lead per ton, and the loss in dressing is the difference in quantity of metal present in the crude ore, and that found in the dressed product, as, for example—

200 tons crude ore of 5 per cent. Pb. = 1000 units.

When dressed yield

16.4 tons dressed ore of 50 per cent. Pb.	=	820 units.
183.6 „ tailings of 0.97 „ „	=	180 „
200		1000 „

The loss being 180 units, the difference between the 1000 units of the crude ore and the 820 accounted for in the dressed mineral.

As a rule the loss increases with the degree to which the ore is concentrated; and with some ores the value of the ore lost becomes, by enriching the mineral, greater than the increased market value of the ore. The only way to arrive at an exact conclusion as to the point at which concentration should be arrested is by actual assay of the crude ore, the various products, and of the steriles; while, if silver is present, as in argentiferous lead, a careful watch must be kept on the slimes in which the greatest loss of the precious metal usually occurs.

The following general rules* will be of use in the formation of an opinion as to the conditions under which the loss will in all probability be small:—

If the ore is fairly hard, and breaks into smaller pieces without much dust of fracture.

If the ore is in itself of considerable density, and consists mostly of large grains easily detachable from a gangue of much lighter specific weight.

If the enriching operation is chiefly confined to hand-picking, and if only a small proportion of the stuff sent to the dressing mill is subject to treatment with water.

On the other hand, the loss of ore and cost of dressing will be considerable.

If the constituents of the ore and veinstone are composed of very small grains uniformly aggregated together.

If the ore and gangue are nearly alike in density.

If the ore is so friable as to disintegrate into powder by the absorption and mechanical action of water.

If the ore is sparingly associated or intermixed with veinstone, or if the veinstone is hard and the ore soft, or if both are subjected to a severe pounding or grinding action.

If the ore in itself bears a high percentage of metal—as in the case of carbonate of copper, 57 per cent.—and simply stains the veinstone.

If a soft ore, thinly distributed or intermixed with hard vein-

* “British Mining,” by R. Hunt. Crosby Lockwood and Son.

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stone, is pounded so as to shatter instead of detaching the ore particles.

TIN DRESSING IN CORNWALL.—The means employed for concentrating tin ore in Cornwall are, as a rule, of the most primitive description, consisting of various forms of flat and round buddles. The great loss in slimes, which amounts to about 50 per cent., has, however, recently brought about the introduction of improved machinery by some of the companies. It is estimated that in 1890 the mines within one mile of Carn Brea threw away £69,206 worth of tin, in addition to that carried to the sea.* The following tabular statement of the Government returns from mines, whose waste waters flow into the Portreath river, show accurately the amount of tin produced by concentration at the mines, and the amount of loss by imperfect concentrating appliances, but recovered by the stream tin workers in the river:—

Mine.	1890.			1891.		
	Tons.	Cwts.	£	Tons.	Cwts.	£
Wheal Basset	396	—	22,203	402	—	22,448
West Basset	310	2	16,471	283	12	14,421
Wheal Uny	141	6	7,982	177	10	9,648
Wheal Agar	261	5	13,287	339	17	17,149
Penandrea	139	—	7,802	76	12	4,334
	1			1		
Totals	1247	13	67,745	1279	1	68,000
	Price per ton, £54 6 6			Price per ton, £53 3 3		
Sold by streamers from } Portreath river	Tons.	Cwts.	£	Tons.	Cwts.	£
	428	—	17,126	330	6	10,469
	Price per ton, £40			Price per ton, £31 14 6		

Percentage of river to mine tin, in quantity, 33 ; in value, 25.
Doubtless the same waste goes on at other mines, so that we cannot doubt but that if improved concentration machinery were

* "Transactions of the Mining Institute of Cornwall," Vol. IV., Part I.
"Paper on the Treatment of Slime Tin," by J. Hicks.

erected, many mines which now struggle along, or are worked at a loss, would then be worked to a profit, by the money which now goes into the pockets of the stream tin workers being turned into those of the mine shareholders without extra cost to themselves.

This question of improved concentrators is becoming all the more urgent from the fact that in depth the tin ore is not found in comparatively large crystals in the gangue, but is more and more finely disseminated through it as depth is reached.

The result of this is that the ores must be crushed finer. As a matter of fact, the mesh of the sieves employed in the stamp batteries has increased in fineness during the last fifteen years, from Nos. 30 and 32 B.W.G. to Nos. 35 and 36. The finer crushing entails the production of a larger percentage of slimes, and, unless improvements are made, the loss of slimes now estimated at from 50 to 80 per cent. will become still greater.

I hesitate to advise the adoption of any particular machine, but from the description of the Linkenbach table, the Frue vanner, the Embrey concentrator, and the Bilharz percussion table already given, those interested in tin dressing will, I think, be able to choose for themselves the machine best adapted to their particular ore.

CHAPTER XIX.

THE MILLING OF GOLD ORES.

Mill for Treating Free Gold—Description of Mill—Cost of Milling—Test for Free Milling and Refractory Ores—Treatment of Concentrates—Mill with Concentrators for Refractory Gold Ores—Specification of 10-Stamp Mill—Power Required—Materials Required for One Month's Run—Cleaning the Plates.

MILLS FOR TREATING GOLD ORES.—The ores of gold may be divided roughly into two classes:—(a) Those in which the gold is in a free or metallic state, or partly so; (b) those in which the gold is associated with the compounds of other metals—usually the sulphides.

In the former case the milling of the gold ores is a very simple matter, and consists principally in reducing the ore to a state of pulp or slimes, by means of a stamp battery, or other pulverising machine, and then passing the pulp over a series of copper plates coated with mercury, or, as it is termed, amalgamated. The particles of gold attach themselves to the silvered surface of the plates in the form of amalgam, which is scraped off from time to time and put into a retort. The mercury is driven off by means of heat, and condensed for future use, while the gold is left in the form of a brown deposit ready to be melted into bars.

Simple as the process seems, it is surrounded with technical difficulties in connection with the pulverising and amalgamation, a few of the principal of which will be briefly pointed out. A full description, however, would require a special treatise, and the reader is referred to that of Mr. M. Eissler on the subject. *

* "The Metallurgy of Gold," by M. Eissler. Third Edition. Crosby Lockwood and Son.

The general arrangement of a mill for treating free gold ores is shown in the section, fig. 214. The ore from the mine arrives by means of the tramway, *a*, which takes it, if possible, direct to the level of the top of the mill. If this is impossible, owing to the configuration of the land, then the ores must be hoisted by mechanical means. It is then tipped over the grizzly or inclined screen of iron bars, *b*, the rough ore being fed into the stone breaker, *c*, while the fine passes through the screen direct into the hopper, *d*, and joins that crushed by the machine.

At the mouth of the hopper or magazine an automatic feeder, *e*, is fixed (see also figs. 138, 139, p. 222), and this regulates the

FIG. 214.—GENERAL ARRANGEMENT OF A GOLD MILL.

supply of the ore to the stamp battery, *f*. The ore, after pulverisation, flows in the form of pulp or slimes through the screens in front of the stamps, and is spread in a thin sheet over the amalgamated plates, *g*. The free gold is caught and retained by the mercury, while the sand and water are conveyed out of the mill. The amalgamated plates are of the same width as the mortar box, and from 6 ft. to 12 ft. long, the usual length being about 8 ft. One or more amalgamated copper plates are also fixed inside the mortar box, and small quantities of mercury are occasionally dropped into the mortar while the stamps are running. The free gold is thus caught both inside and outside of the battery, and as it accumulates in the form of amalgam it is scraped off and retorted.

The stamps are usually fixed in one long row, so that the illustration will equally apply to a battery of 10 or 100 stamps.

When Huntington mills, or other special forms of pulverisers are used, they are fixed in the same position as that occupied by the stamps, and are followed by amalgamated plates.

The motive power may be either steam, water, or electricity, and is applied to the main driving shaft, *h*.

This process of milling is one of the cheapest possible, and in large mills will not cost more than 16s., or say 60 cents per ton of ore; so that ore of a value of 16s., or say, \$4 can be mined and milled to a profit, while under exceptionally favourable circumstances, with water-power and large masses of ore, a profit can be made out of mineral worth only 4s. per ton.

There are, however, but very few cases in which the ore is sufficiently free as to permit of its successful treatment by amalgamation only. It is usually allied with other minerals in the form of sulphides, such as those of iron, copper, lead, and zinc, as well as with the tellurides, selenides, and antimonides of the metals; so that the gold, or a large portion of it, is so locked up with these impurities as to be unattackable by the mercury on the plates, and passes away with the sulphides. In some cases the loss of gold which thus occurs is not sufficient to cover the cost of concentration; but wherever the sulphides contain a payable amount of gold, it is necessary to put up a complete set of fine concentration machinery. As a certain proportion of the gold is usually in a free state, the whole of the ore must, as a preliminary, be reduced to the state of slimes, in order that it may be passed over amalgamated plates; and, as a consequence, the concentration machinery must be such as is adapted to the treatment of slimes.

A rough idea as to the proportion of free gold in a sample of ore may be obtained by reducing it to powder in a clean pestle and mortar, and then concentrating it by panning. If the concentrates are now rubbed with mercury the free gold will be extracted, and the amount of gold in the residue may be found by assay. It often happens that lodes, or reefs, carry gold in the free state on, or near, the surface, and as depth is gained the character of the ore gradually changes, and the sulphides, which near the surface had become decomposed, now predominate,

necessitating the addition of concentrating machinery to the mill, so that samples taken from the outcrops of the reef, or even from shallow workings, must not be regarded as definitely proving that the gold is free. In erecting a new mill, on the supposition that the gold exists in a free state, it is advisable to arrange for the future addition of concentrating machinery; and if Frue vanners are to be employed, it is usual to estimate for two of these for each five head of stamps, or for each Huntington mill.

The extra cost of concentration, once the machinery is erected, is not great, nor do the machines absorb much power, as will be seen from the separate descriptions given of those usually employed.

The concentrates obtained may either be sold as such, or undergo the further processes of roasting and chlorination, or treatment by the cyanide method, for the purpose of obtaining the gold in a metallic state, on the mine itself, according to the local facilities.

Most of the ores of gold contain a certain amount of silver which, in the case of free milling ores, is recovered with the gold in the concentrations, and can be extracted equally well, either by melting or pan amalgamation, or by some modifications and additions to the chlorination process. Where the amount of silver is considerable the ore should be classed as silver milling and be treated as such, as described on page 365.

GOLD MILL WITH CONCENTRATORS. — The general arrangements of a gold mill with concentrating machines will be seen in figs. 215 and 215A, which are a plan and cross-section of the 60-stamp combination gold mill, with copper amalgamating plates and Frue vanners, as erected by Messrs. Fraser and Chalmers, for the Montana Company, Limited.

The ore enters the mill by a tramway at *a*, and is emptied first into the hoppers, *b*, above the stone breakers, which form reserves of ore, should there be any hitch in the delivery of the ore to the mill. From these bins the ore slides over inclined screens, or grizzlies, *k*, the fine stuff passing direct into the lower bins, *e*, while the coarse is crushed in the stone breakers, *d*, of which there are three, and then also falls into the bins, *e*. The twelve automatic feeders, *ff*, regulate the supply of ore from the bins to the line



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GOLD OPES

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- 2 high mortars or batteries, each about 5000 lb. weight, planed upon bottom and for screen frames, foundation bolt holes drilled by template, mortars arranged inside for receiving copper lining front and back.
- 2 hard wood screen frames, fitted to mortars.
- 4 wrought-iron keys, for holding screen frames in place.
- 2 Russia iron slot punched screens, of such size as may be required.
- 10 patent stamp shoes, made from white iron, with soft grey iron necks.
- 10 dies, of best quality white iron.
- 10 heads, bored for stems and recessed for shoe stem.
- 10 stems, both ends tapered, made from best refined iron. Ends being tapered, when one end breaks the stem can be reversed and other end used.
- 10 tappets with wrought gib and steel keys, all properly fitted to place.
- 10 cams (5 right and 5 left hand) fitted to cam shaft with steel keys, all properly marked to place, to give proper drop.
- 1 heavy hammered iron cam shaft, turned full length and key-seated for pulley and cams.
- 2 wrought collars and steel set screws, fitted to cam shaft.
- 3 heavy corner cam shaft boxes, babbitted and bored, planed upon back and furnished with bolts and caps.
- 2 jack shafts, not turned.
- 4 jack shaft boxes.
- 10 iron sockets for wood levers, lined with leather.
- 10 wood levers or finger pieces, for holding up stamps, fitted to sockets.
- 1 pair of double sleeve flanges for wood pulleys, turned and fitted together, with woodwork built up, hub key seated, wood work turned up and painted, and securely bolted through flanges.
- All bolts, rods, nuts, and washers, for 10-stamp framework complete, including all holding-down bolts and washers for mortars.
- 1 complete set of hard wood guide boxes, all worked out for stamp stems, with all guide bolts, nuts, and washers.
- 2 pieces of rubber packing, $\frac{1}{4}$ in. thick, for top of mortar blocks, for mortars to rest upon.

Water Pipes :—

- 1 complete set of water pipes for 10 stamps proper, with valves and fittings ready for connection with main supply ; also hose for washing copper plates in front of mill.

Copper :—

- 2 sheets of pure L. S. copper, 96 in. \times width of mortar $\times \frac{1}{8}$ in., for tables in front of mill.
- 2 sheets of pure L. S. Copper, $\frac{3}{8}$ in., for mortars inside, all fitted.
- 2 sheets of pure L. S. Copper, $\frac{3}{8}$ in., for mortars inside, all fitted.

Building Bolts :—

1 complete set of building bolts, rods, nuts, and washers, for frame of building, and also for ore bins.

Tighteners :—

1 stamp tightener for stamp belt, complete with wood frame, rack, pinion, hand wheels, dogs, etc.

1 breaker tightener for breaker belts, complete, with swinging frame, chain, shaft and hand wheel.

1 main tightener for engine belt, complete, with wood frame, rack, pinion hand wheel, dogs, etc.

Shafting, Pulleys, and Belting :—

1 main line turned shaft, $3\frac{1}{2}$ in. diameter \times 11 ft. 3 in.

3 pillow blocks for $3\frac{1}{2}$ in. shaft.

1 pulley, 32 in. \times 15 in., to drive stamps.

1 pulley, 42 in. \times 14 in., on engine shaft, to drive main line shaft.

All necessary bolts for pillow blocks.

All necessary collars and set screws.

1 turned shaft, $2\frac{1}{2}$ in. \times 8 ft. 6 in. for driving crusher.

2 pillow blocks, for $2\frac{1}{2}$ in. shaft.

1 pulley, 60 in. \times 14 in., to receive power from engine.

1 „ 36 in. \times 10 in., to drive crusher countershaft.

1 „ 24 in. \times 10 in., on crusher countershaft.

1 „ 40 in. \times 8 in., to drive crusher.

All necessary bolts for pillow blocks.

All necessary collars and steel set screws.

1 rubber belt, 45 ft. \times 14 in., 4-ply, for battery.

1 belt, 49 ft. \times 14 in. \times 4-ply, for engine.

1 „ 70 ft. \times 10 in. \times 4-ply, for crusher countershaft.

1 „ 47 ft. \times 7 in. \times 4-ply, for crusher.

1 „ 27 ft. \times 5 in. \times 3-ply, for engine belt feed pump.

1 hide of lace leather.

Amalgam Safe :—

1 amalgam safe and strainer, with padlock.

Retort and Bullion Furnace :—

1 retort, complete, with cover, wedge, and condenser.

1 16-in. bullion furnace, with all ironwork, one set of crucible tongs, 2 gold bullion moulds and one set of steel letters for stamping bullion.

Overhead Crawl and Block :—

1 overhead carriage crawl and track iron, with wood screws for same.

1 1-ton differential pulley block.

POWER.

Engine :—

- 1 stationary slide valve steam engine, cylinder 9 in. bore \times 14 in. stroke, complete, as per specifications attached (This engine has power for driving the above described machinery only, together with two or four Frue vanners if required.)

Boiler :—

- 1 tubular steam boiler, 40 in. diameter \times 10 ft. long, complete with all fixtures and trimmings, breeching and smoke stack.

Feed Pump, Heater, and Pipes :—

- 1 belt feed pump, 2 \times 3.

- 1 heater, with pipe coil.

All pipes, valves, and fittings for steam, water, and exhaust to make power complete, plans of which are furnished by the manufacturers.

Total approximate weight, 60,000 lb.

POWER REQUIRED FOR A 10-STAMP WET-CRUSHING GOLD MILL, WITH
CONCENTRATORS AND AMALGAMATING PAN.

1 "Blake" rock breaker, No. 2	=	6	horse-power.
2 ore feeders	=	0	"
10 stamps, 750 lb., 90 drops	=	12	"
4 Frue vanner concentrators	=	2	"
1 grinding pan, 3 ft. diameter	=	3	"
1 settler	=	3	"
Friction	=	4	"
<hr/>			
Total	=	30	"

The above form of mill is capable of working 15 to 18 tons per day of twenty-four hours.

ESTIMATES OF MATERIALS, SUPPLIES, ETC., REQUIRED FOR A 10-STAMP
GOLD MILL FOR ONE MONTH'S RUN.

Note.—Bracketed numbers refer to corresponding numbers below.

- [1] 10 gall. lard oil, in $\frac{1}{2}$ shipping cases.
- [2] 10 ,, cylinder oil, ,, ,,
- [3] 50 ,, coal ,, ,, ,,
- [4] 25 lb. tallow or compound.
- [5] 6 boxes axle grease.
- [6] 1 box candles.
- [7] 50 lb. cotton waste.
- [8] 10 lb. assorted packing for engine, valves, etc.
- [9] 1 yd. $\frac{1}{4}$ -in. sh. rubber for gaskets, etc.

STORES AND MATERIALS FOR A 10-STAMP MILL. 363

- [10] $\frac{1}{2}$ pint each of sulphuric and nitric acid.
- [11] 5 lb. each cyanide of potassium and concentrated lye.
- [12] 1 oz. metallic sodium.
- [13] 4 oz. prepared amalgam.
- [14] 3 flasks mercury (230 lb.).
- [15] $\frac{1}{2}$ doz. whisk brooms.
- [16] 1 fine sponge.
- [17] 1 yd. 8 oz. cotton duck.
- [18] 2 amalgam knives.
- [19] 1 stone mortar and pestle.

Approximate cost, \$270.00.

REMARKS.

Note.—Bracketed numbers refer to corresponding numbers above.

- [1] Lubricants of all kinds are generally wasted by ignorant or careless employés. We have allowed liberal quantity here.
- [2] With care and proper oil cups, much less quantity is sufficient.
- [3] Dependent on season and latitude and number of mill lanterns.
- [4] For stone crusher and shafting bearings.
- [5] For cams, applied properly, it gives a coating which thereafter needs a mere touch of grease.
- [6] About six candles will be consumed per night. (Incandescent electric lights are cheaper than candles after first expense is incurred.)
- [7] After rejected by engineer, should be washed and used on shafting and rock breaker.
- [8] Kind dependent on engine, quantity sufficient to repack, say once a month.
- [9] Necessary for packing gaskets and screens, etc.
- [10] Useful only to burn cast iron, copper, etc., from the residuum after clean-up, where gold or amalgam exists.
- [11] See remarks further on.
- [12] For cleaning mercury after retorting.
- [13] Use on plates in first starting of a mill, if running continuously, thereafter not necessary.
- [14] See remarks further on.
- [15] See remarks further on.
- [16] For taking sand, etc., from surface of amalgam and mercury.
- [17] For squeezing amalgam.
- [18] For use on plates.
- [19] For grinding small lots of amalgam.

The above estimate is what should be ordered if it is required to run a 10-stamp mill in perfect condition for one month. (No lubricants to be expended for mine pumps or other machinery.)

All mill supplies should be placed under lock and key, and employés forced to be strictly economical in their use, and, where necessary, instructed in the same. In ordering a six months' supply, multiply by six, and deduct 10 per cent. Should supplies fall short, there is a waste of material needing correction.

Cyanide of potassium is useful in coating the plates with mercury, or when, from the presence of arsenic, sulphur, etc., or heavy concentrates, the plates become discoloured or blackened. The indiscriminate use of above, or acids, is to be strongly condemned. Verdigris appears to be the *bête noire* of amalgamators, and the reasons for using acids and alkalies indiscriminately only serves to alter the nature of the copper plates; this never should be done. In case of a mill started for the first time, a small quantity of prepared amalgam, spread equally over the upper half of the plate, will be useful in excluding the air (oxygen) from the plates, and prevent verdigris (oxide of copper in this case) on ore running from, say, \$5 per ton and upwards. Every two or three days other things, such as the use of mercury feeding the batteries, and proper brushing, will be sufficient to conquer the verdigris. Whisk brooms are best to brush the plates; these brooms should be cut to one-half their usual length, so as to give a good stiff brush. The plate should be brushed hard over every inch of its surface, and the amalgam thoroughly loosened from the plate. Then commencing at the top of the plate, where the most amalgam will be formed, with stiff brushes the amalgam should be removed perpendicularly (not brushed to the centre) to the lower portion of the plate, where the surplus amalgam should be removed. This leaves a thin coating of amalgam over the entire surface of the plate, excluding the air, and preventing verdigris. If plates are not run too wet (excess of mercury) this method will never fail to prevent oxidation. Acids and alkalies only serve to precipitate verdigris after a few days, or form salts of copper, which pop off only to return as an oxide, with tenfold power and quantity. In brushing the plates, a weak solution of cyanide of potassium (in case of heavy concentrates) and concentrated lye (weak) in case of grease on the plates may be used.

CHAPTER XX.

THE MILLING OF SILVER ORES.

Free Milling Ores—Roasting Milling Ores—Combination Process—Wet Crushing Silver Mill—Specification for 10-Stamp Wet Crushing Mill—Power and Water Required—The Working of the Mill—Amalgamating Pans and Settlers—Blanket Tables—Sand Sluice—The Boss Continuous Process.

THE ores of silver, like those of gold, are divided, for milling purposes, into two general classes: (*a*) Free milling ores, or those which can be amalgamated direct after pulverisation; and (*b*) Roasting ores, which, before amalgamation, require a preliminary roasting. The free milling ores are crushed in a wet, and the roasting milling in a dry state.

FREE MILLING ORES.—The minerals which contain the silver in such a form, that it can be brought into contact with, and amalgamated by, mercury, either with or without the aid of chemicals in the amalgamating pans, are those best suited for the free milling process, and are those which contain native silver, chloride of silver, and sulphide of silver in certain forms. On the other hand, those silver ores which are mixed with the sulphides of iron, copper, lead, zinc, and antimony, are not adapted to a free milling process, owing to the presence of the base metals interfering with the amalgamation, either by setting up chemical reactions of their own, and so fouling the mercury, or through their being combined with the silver in such a way that something more than the mechanical action of pulverisation is required to separate them.

The deposits, veins, or reefs of silver ores, like those of gold, are often free milling at or near the surface, where they have been subject to the decomposing action of the atmosphere, but gradually become refractory as depth is gained, so that the mineral obtained beyond a certain depth is no longer free milling, and must be roasted before it can be amalgamated. The line of demarcation between the two classes of ore is never very definite, so that it sometimes happens that a certain amount of loss must be put up with when the ore is in the transition state, and before it becomes entirely refractory, as the process of free milling is cheaper than that of roasting milling.

The decomposed silver ores just mentioned, together with occasional natural deposits of chloride of silver, and still rarer ones of native silver, comprise those which can be advantageously treated by the free milling process.

The cost varies greatly, according to local conditions, price of labour, fuel, water, and materials, and also with the use of steam or water as a motive power.

The limits are from 15s. to 40s. per ton of ore. The former price can only be reached by large mills, having exceptional facilities, driven by water-power. The number of men employed in a 25-stamp mill, with 10 amalgamating pans, having a total capacity of from 50 to 55 tons of ore per 24 hours, would, in a well-managed mill, be fifteen, and the cost of labour would be from 6s. to 9s. per ton of ore, while the amount of silver saved would vary from 60 to 80 per cent. of the assay value of the ore. A wet crushing silver mill is described on page 368.

ROASTING MILLING ORES.—The number of ores which can be subjected to the free milling process are few, as compared with those which can be treated by the roasting milling operation which consists in roasting the ore in a suitable furnace with salt, previous to its amalgamation in pans, or treatment by the lixiviation or leaching process described on page 394. The roasting drives off the sulphur, and converts the silver into chloride of silver, in which state it can be amalgamated; it, however, entails loss of silver, especially when the ore contains arsenic or antimony; and this loss will vary according to the nature of the ore, and the type of furnace used, from 2 to 25 per cent. of its contents in

silver. The amount of silver which can be recovered by amalgamation is estimated at from 90 to 95 per cent. of that contained in the ore after roasting, and the cost of the process, which necessitates dry stamping and heavier machinery, is from 32s. to 60s. per ton of ore.

In addition to the two processes of silver milling above mentioned, which are adapted to two distinctly different classes of ore, there is another which is more especially valuable for the treatment of many gold and silver ores, either when separate or combined, in which the amount of foreign sulphides is not sufficient in quantity to permit of the use of roasting, and is yet so great as to militate against the successful and economical use of free milling.

THE COMBINATION PROCESS to which we refer is especially adapted to this class of ore, and is, briefly, wet crushing, followed by amalgamation over copper plates if free gold is present, then concentration by means of Frue vanners, or other fine concentrators, and finally the pan amalgamation of the tailings, either by settlement previous to amalgamation, or by the Boss continuous process, described on page 382.

The result of this arrangement is that the free gold is caught on the plates, the refractory ores and sulphides are enriched and concentrated into a small bulk, and any value left in the tailings is recovered by the pan amalgamation. The advantages claimed by the advocates of this process are—

1. The grinding in the pans is lessened or entirely dispensed with, and the wear and tear of castings is either decreased or done away with, and there is a consequent saving in fuel and motive power.
2. The loss of quicksilver is decreased.
3. Coarser crushing, and therefore increased capacity of the stamps is possible.
4. Bullion of a higher grade is obtained.
5. The total percentage recovered is increased, and varies from 75 to 85 per cent. of the silver in the ore.

The cost of the process is from 12s. to 40s. per ton, and in the case of the Montana Company, Limited, the adoption of this process resulted in a total saving of from 32s. to 40s. per ton over

simple pan amalgamation, while the loss of mercury decreased by $\frac{3}{4}$ lb. per ton of ore, and the grade of the bullion rose from 500 fine up to 900 fine.

SILVER MILL, WET CRUSHING.—The general arrangements of a wet crushing silver mill will be seen in the section, fig. 216. The ore arrives from the mine by the tramway, at *a*, and is tipped down a chute to the level of the mouth of the stone breaker, *b*.

The crushed ore is received in the bin, *c*, and is automatically fed into the stamps, *c*, by means of the feeder, *d*. The crushed pulp flows into the tanks, *ff*, where it settles, and the excess of water is drained off. The thick pulp is shovelled into the amalgamating pans, *g*, in regular charges, and is worked for several hours together with a mixture, first of salt and sulphate of copper and other chemicals, and finally with additions of quicksilver. A perspective view, showing two amalgamating pans, *gg*, and one settler, *h*, is given in fig. 223.

When the operation of amalgamation is finished, the contents of the pans are run off into the settling tanks, *h*, in which the pulp is thinned down with water, and stirred gently so as to allow the quicksilver and amalgam to settle to the bottom, after which the slimes are run off, either to waste, or, as in some cases, are treated on fine concentrators, with a view to the recovery of any remaining value in them, as in the description of the Boss process on page 382.

The amalgam which has settled to the bottom of the tanks, *h*, is drawn off and strained, in order to get rid of the excess of mercury, and is then retorted, and the resulting mass of gold and silver melted into bars in the furnace, *i*.

In the old mills the quicksilver was carried about by hand, to the points at which it was required. In the modern mills, however, it is hoisted by means of the elevator, *j*, to the collecting tank, *k*, from which it is conducted by pipes to the machines which use it.

It is reckoned that 5 stamps will crush sufficient ore to keep 3 pans going, so that a 10-stamp mill, such as the one just described, would require 6 pans and 3 settlers, and also 1 clean-up pan, of which particulars will be found on pages 376-380.

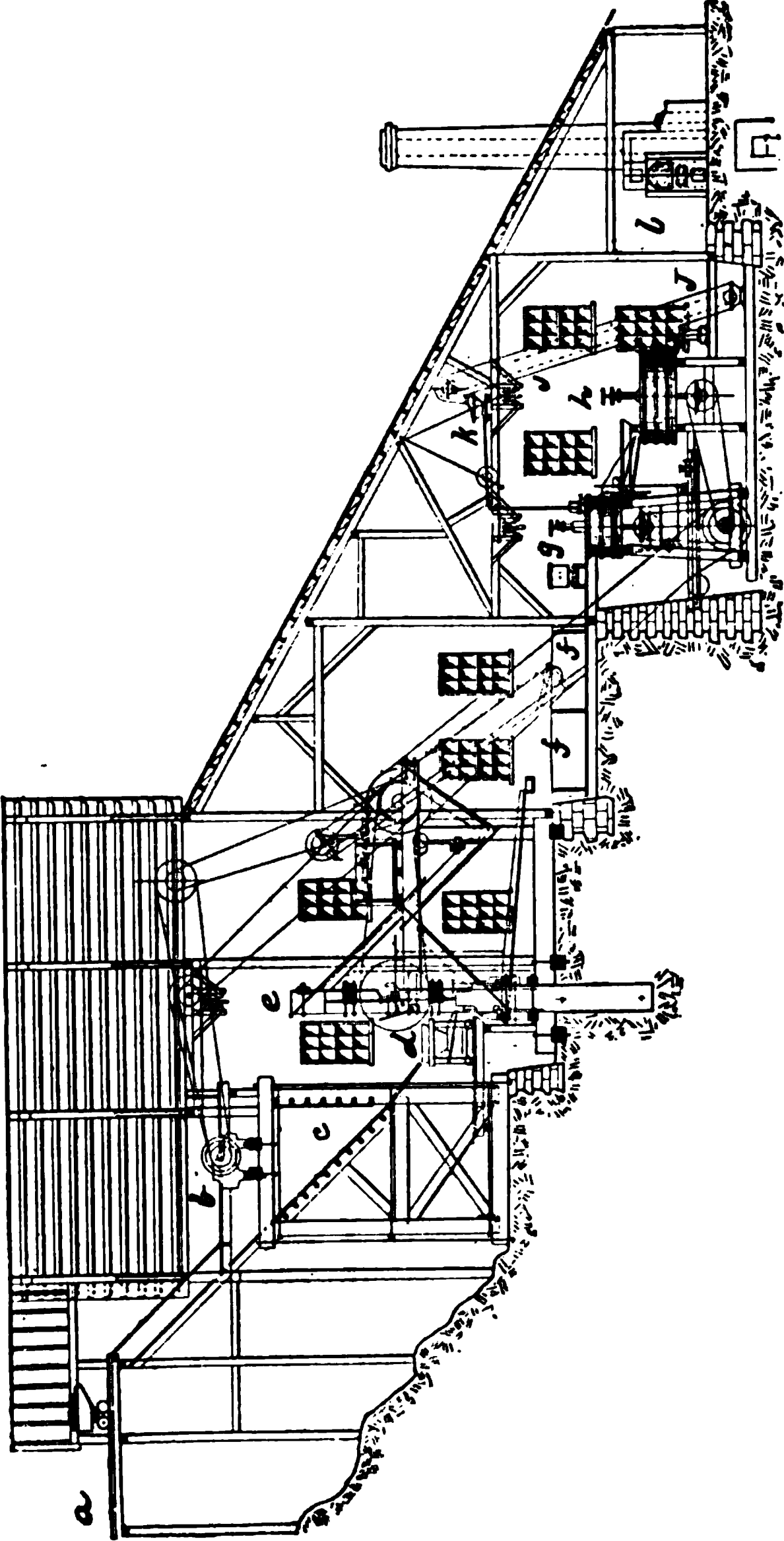


FIG. 216.—SECTION OF A WET CRUSHING SILVER MILL.

The following is a complete specification of the machinery used in a mill such as that just described :—

SPECIFICATIONS FOR 10-STAMP WET CRUSHING SILVER MILL.

Crusher :—

- 1 10 × 7 in. Blake crusher, to be furnished complete, ready to run when set in place.
- 1 duplicate set of jaw plates for above crusher.

Grizzly :—

- 1 Grizzly, or ore screen, for relieving breaker, size 4 × 10 ft. complete.

Automatic Feeders :—

- 2 Tulloch improved automatic feeders complete, with wood frames and sheet iron hoppers. All necessary track iron, punched and countersunk with wood screws for laying same for feeders to operate upon.

Stamps :—

- 1 10-stamp mill of improved design, each stamp weighing 850 lb., arranged to run in one battery of 10 stamps by belt and tightener from stamp countershaft, complete in detail as below.
- 2 high mortars or batteries, double discharge, all to be complete with screen frame and faces planed ; also planed upon bottom for resting upon foundation. The bolt holes drilled by template.
- 4 hard wood screen frames fitted to mortars.
- 8 wrought-iron keys for holding screen frames in place.
- 4 Russia iron slot punched screens, of such size as may be required.
- 10 patent stamp shoes, made from white iron, with soft grey iron necks.
- 10 stamp dies of best quality white iron.
- 10 stamp heads, bored for stems, and recessed for shoe stem.
- 10 stamp stems, made from extra fine iron, both ends tapered ; when one end breaks the stem can be reversed and other end used.
- 10 stamp tappets, with wrought-iron gib and steel keys all properly fitted to place. Tappets faced on ends.
- 10 cams (5 right and 5 left hand) fitted to cam shaft with steel keys all properly marked to place to give proper drop.
- 1 heavy hammered iron cam shaft, turned full length, key-seated for cams and driving pulley.
- 2 wrought-iron collars with steel set screws, fitted to cam shaft.
- 3 heavy cam shaft boxes, babbitted, hammered, and bored, planed upon back, and furnished with bolts and caps.
- 2 jack shafts, not turned.
- 4 chairs, or sockets, for jack shafts to rest in.
- 10 iron sockets for wood levers, lined with leather, for stamp holders.
- 10 wood levers, or finger pieces, for holding up stamps, fitted to sockets,

1 pair of double sleeve flanges for wood pulley, turned and fitted together with woodwork built up between, hub key-seated, woodwork turned up and painted and securely bolted through flanges, to be fitted with steel key, properly marked to place.

All necessary bolts, rods, nuts, and washers for 10 stamp framework complete, including all holding down bolts and washers for mortars.

1 complete set of hard wood guide boxes, all worked out for stamp stems, with all guide bolts, nuts, and washers.

2 pieces of rubber packing, $\frac{1}{2}$ in. thick, for top of mortar blocks for mortars to rest upon.

Water Pipes :—

1 complete set of water pipes for 10-stamp mill, including all valves, water cocks, and fittings for supplying each stamp with water. Connection to be prepared to receive water from main supply. (The piping actually furnished does not include sufficient to connect with main supply.)

Combination Pans :—

4 improved combination amalgamating pans, each 5 ft. diameter, with wood staves, to be furnished with upright cone in bottom; upright spindle fitted with separate steel toe; 2 hand wheels and screw on top of spindle for raising Muller nut for screw; driver sleeves; driver arms separate from sleeves and bolted to same Muller plate; 8 cast-iron shoes and 8 cast-iron dies to each pan; wrought-iron bands and lugs for staves; step box fitted on plate, which also carries one bearing of countershaft; step box fitted with steel buttons and bushings; countershaft; driving pulley; out end bearing for shaft. All bolts for boxes for bolting to framework.

Settlers :—

2 8-ft. combination settlers complete, the same in detail as pans enumerated above, with the exception of shoes and dies. Wooden shoes to be furnished with settlers.

Clean-up Pan :—

1 48-in. clean-up pan, all complete as usually furnished, the same as pans detailed above.

Retort :—

1 12-in. silver retort, all complete, with cover bar and hand screw for holding cover in place; carriers; fire front complete, with fire door and liners, dead plate, back bearer, double grate bars, condensing pipe, cast-iron ash pan; all necessary wall binders and rods for bracing brickwork.

1 set of castings for 16-in. bullion furnace complete, including top cover bearing bars, grate bars, anchor bolts, etc.

6 assorted black lead crucibles and covers.

1 set of trays or cups for holding amalgam.

- 1 pair crucible tongs.
- 1 set of bullion moulds, three in number, assorted sizes.
- 1 set of steel numbers for stamping bullion bars.
- 1 iron floor plate, punched and countersunk, with wood screws for laying same for retort room floor.
- 1 smoke stack for retort bullion furnace, of suitable diameter and length, with base plate and guys for staying stack.

Quicksilver System :—

- 1 complete quicksilver elevator, with rubber belt, Russia iron cups, and all fixtures and fittings required for making elevator complete, including
- 1 upper and lower quicksilver tank.
- 2 quicksilver charging pots.
- All pipes, iron cocks, and fittings for the complete quicksilver circulating system that may be required to make same complete.

Overhead Crawls :—

- 3 overhead carriage crawls complete.
- 2 2-ton differential pulley blocks.
- 1 1-ton differential pulley block.
- All necessary track iron, punched and countersunk, with wood screws for laying same for overhead crawls to run upon.

Piping :—

- All necessary water pipes, valves, and fittings for the complete mill, for supplying pans and settlers with the necessary steam and water, ready to receive connection with main supply.

Tighteners :—

- 1 crusher tightener complete.
- 4 pan tighteners complete.
- 1 stamp tightener complete.

Shafting, Pulleys, and Belting :—

- All necessary shafting, pulleys, boxes, and belting for driving all of the above described machinery in accordance with our drawings.
- All the belting throughout the entire mill to be Boston Belting Company's best brand.
- All pulleys to be turned, faced, and balanced ; pillow blocks to be planed upon bottom and lined with best babbitt metal and bored out ; couplings to be fitted to shaft with keys, to be turned and faced ; all bolts to be furnished for all bearings ; all key-seats to be cut in shafts so as not to be in bearings.

Building Bolts :—

- All necessary bolts, rods, nuts, and washers for the complete framework of mill building in accordance with our drawings as usually furnished.

STEAM POWER.

Engine :—

- 1 Fraser and Chalmers' slide valve engine with Corliss style frame, size 14 × 24 in., all complete in detail.

Boilers :—

- 2 Fraser and Chalmers' tubular steam boilers, each 48-in. diameter × 14 ft. long, complete in detail.

Heater :—

- 1 24-in. tubular steam heater complete, including galvanised iron pipe for passing through roof.
 1 No. 3 Knowles' steam boiler feed pump.
 All necessary pipe connections for properly connecting engine, boiler, heater, and feed pump.

Total approximate weight, 175,000 lb.

The mill as covered by specifications is complete and automatic.

The power required for working the above 10-stamp wet crushing silver mill to a capacity of from 18 to 20 tons per 24 hours, would be :—

1 Blake rock feeder, No. 2	.	.	.	.	6 horse-power.
2 ore feeders	.	.	.	.	0 „
10 stamps, 750 lb., 90 drops	.	.	.	.	12 „
6 grinding pans, 5 ft. diameter	.	.	.	.	30 „
3 settlers, 8 ft. diameter	.	.	.	.	9 „
Friction	.	.	.	.	7 „
					—
Total	.	.	.	.	64 „

The water required for the whole mill will be 2200 gallons per hour.

THE WORKING OF A WET CRUSHING SILVER MILL.—It is not within the scope of the present volume to enter into full practical details of the various milling plants described ; all that can be done is to give the general outlines of the working of the processes, and refer the reader to some of the numerous treatises which have been written on these subjects.

For the details of silver milling my readers cannot do better than study "The Metallurgy of Silver," * which they will find full

* "The Metallurgy of Silver," by M. Eissler. Second edition. Crosby Lockwood and Son.

of practical information, and in more detail than in the following notes, for many of which I am indebted to the courtesy of Messrs. Fraser and Chalmers, the well-known constructors of machinery.

Crushing.—At the outset we come across a disputed point as to the crushing of silver ores. Formerly it was the universal system to crush coarse in the batteries, and then use the pans for the grinding of the ores, a system which entailed great wear and tear in the pans, a greater loss of quicksilver, and also a greater expenditure of power, while the fine grinding in the pans forced the quicksilver to saturate itself with foreign matter, and rendered it inert for the amalgamation of the gold and silver. The opposite

FIG. 217.—THE ARRASTRA.

method is to stamp fine in the batteries, and use the pans for amalgamation only, and not for reducing the ore still finer by grinding; and, strange as it may seem, it is very probable that better results can thus be obtained than by the former and more ancient method.

Amalgamation.—The modern amalgamating pan, such as is shown in figs. 218, 219, is the development of the old Spanish-American Arrastra, of which, for the sake of comparison, an illustration is given in fig. 217. Some of the pans are provided with a false bottom, forming a steam chamber, as in fig. 237, while in others the steam is introduced direct into the pulp, for the purpose of heating it, by means of a pipe. The pan holds

from $1\frac{1}{2}$ to 2 tons of pulp, according to its size, and water is mixed with it as it is shovelled in from the settling tanks, in such

c

FIG. 218.—AMALGAMATING PAN.

a quantity as will enable it to keep the finely-divided globules of quicksilver in a state of suspension throughout its mass, and yet not so thick as to prevent its free circulation.

The heat should be kept at about 200° Fahr., and the muller, which at first does not touch the grinding surface, is gradually lowered, and allowed to grind either with its full weight or otherwise, according to the class of ore. In the course of two hours or so, the pulp is reduced to the required condition, and quicksilver is then scattered over the contents of the pan in the proportion of about 1 lb. per 20 lb. of ore, the muller being slightly raised so

FIG. 219.—AMALGAMATING PAN

as to prevent the mercury from being too finely divided, the speed being from 60 to 70 revolutions per minute.

This is kept up for another two hours, during which time it is the practice of most millmen to add certain chemicals, with a view to assist the process of amalgamation. In former times most absurd decoctions were used for this purpose by millmen, blindly ignorant of chemistry and chemical reactions; now, however, they are confined to two—viz., salt and sulphate of copper; and seeing that some mills use one, some the other, while others use none of

either, it is just possible that neither is beneficial or essential to the different working of the ore in the pans. A more important point which is often neglected, which may involve the saving or loss of many dollars per day, is the pulp current, which must be uniform and regular in order to insure uniform work, and must be strong enough at the bottom of the pan to carry the mercury with it. The motion of the revolving muller makes a current by throwing the pulp to the outside as it advances, which then rolls up the side and is curved over by the wings, which are in the form

FIG. 220.—THE SETTLER.

of inverted ploughshares, and is then thrown down to the centre again. The current above the muller is thus of necessity a good one, and it is desirable that the one underneath should be equally good.

From the amalgamating pans the pulp flows at the end of the operation into the settler placed immediately below. There are many varieties of settlers, but the general form is shown in fig. 220. The object of the settler is to keep the pulp in gentle motion, at the same time diluting it with water to such an extent that the heavier particles of quicksilver and amalgam will separate from the

mass and fall to the bottom. With this object in view the two points to be regulated are the speed of the muller and the quantity of water used. If the speed is too great the quicksilver will be prevented from coming to rest on the bottom, if too slow then the sand will settle with it. If too much water is added the sand will not be kept in suspension, and will settle with the mercury, if too little is used then the pulp will be too thick for the mercury to separate from it.

The quicksilver and amalgam from the settlers is run off at stated intervals and strained through a filter. The quicksilver is

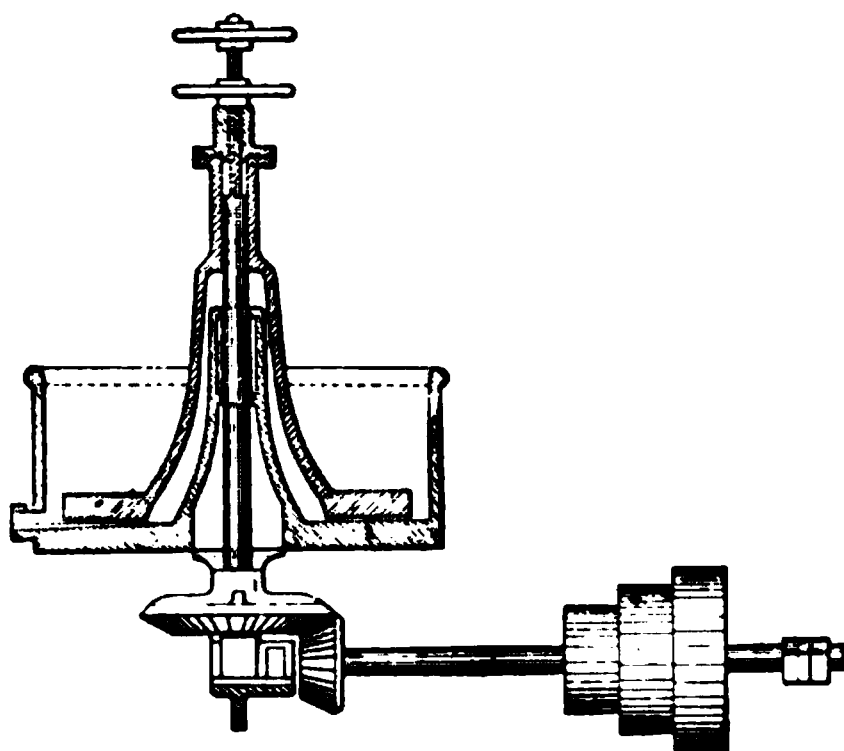


FIG. 221.—CLEAN-UP PAN.

returned to the mill by means of the elevator, and the amalgam, if dirty and impure, is worked up with additional quicksilver in a clean-up pan, such as is shown in fig. 221; after which it is retorted in order to separate the gold and silver from the mercury. The bullion is melted in a wind furnace and cast into ingots ready for sale. The mercury driven off by the heat of the retort is condensed and is then ready for the mill again.

The mixture of sand, water, and various finely-ground sulphides from the settler is sometimes allowed to run to waste; but when it contains ore of any value, it is usual to endeavour to concentrate it by some cheap means. For this purpose it may be treated in agitators which are a supplementary form of settler, or in any of

the appliances used for fine concentration, provided that there is sufficient value in the ore to pay for the process.

The general arrangement of amalgamating pans and settlers in a mill is shown in fig. 223, in which *g g* are a pair of pans, and *h* is the settler, and further details will be found on page 412.

Blanket tables and *sand sluices* are both very effectual. The former is a long shallow trough about 20 in. wide, with sides from 1

FIG. 222.—CLEAN-UP PAN.

to 2 in. high, and of an indefinite length, and may be as long as 300 ft., with a fall of from $\frac{1}{2}$ to 1 in. per foot. They are covered with coarse blankets cut into long strips, in the fibre of which the heavier grains of sulphides and particles of amalgam are retained. The blankets are taken up from time to time and washed in clean water, the stream of tailings being diverted in the meantime down a parallel line of blanket troughs. The concentrates thus obtained are worked up in pans, and usually realise from £4 to £6 per ton,

thereby materially adding to the milling returns, and reducing the original cost of crushing and amalgamation.

Blanket tables are shown below the plates in fig. 163 of Hornsby's battery.

The *sand sluice* can be employed with advantage wherever

FIG. 223.—AMALGAMATING PLANT.

blanket sluices are used, and if placed before them will relieve them from much coarse and heavy material. They are formed of a long shallow wooden trough from 20 in. to 24 in. wide, in which vertical guides are placed at intervals of from 8 ft. to 10 ft. Into these guides thin riffle pieces are slipped, which act as shallow dams; the sands run over these for a time, say for one or more

hours, when another course of riffles, $\frac{1}{2}$ in. or so thick, is laid on top

a

a

FIG. 224.—30-STAMP SILVER MILL, BOSS CONTINUOUS PROCESS. GROUND PLAN.

of the others. This is repeated until the sluice is full, when it is shovelled out, the tailings in the meantime running through a

duplicate sluice The inclination at which the sluice is laid is about $3\frac{1}{2}$ in. in 16 ft. The current is then under control ; for, by starting with a thin riffle at the bottom, a strong current may be obtained, and a thick one will reduce it as may be required.

THE BOSS CONTINUOUS PROCESS.—In the process of wet crushing of silver ores, which has just been described, it will have been noticed that the pulp, after leaving the battery, is allowed to settle in vats, and that the solid matter is then shovelled into the amalgamating pans. All this handling is costly, and takes up time, and the attention of inventive men has long been turned to devising some scheme by which it could be avoided, so that the pulp

FIG. 225.—SECTION OF A 30-STAMP SILVER MILL, BOSS CONTINUOUS PROCESS.

might flow on in a continuous stream from the screens through the grinding, amalgamating, and settling pans, leaving its rich contents on the way, and passing from the mill in the state of sterile slimes, without its progress being interrupted by any settling tanks. Mr. M. P. Boss, an American metallurgist, has devised and put into successful practice such a process, which bears his name ; and, from the experience already gained, it would appear that it can be successfully applied to any ores adapted to the ordinary pan treatment, and effect a considerable saving in time and cost.

A plan and section of a 30-stamp silver mill for the Boss continuous process is given in figs 224 and 225. The ore from

the mine arrives by the tramways, *a, a*, and is tipped over the grizzlies, *b, b*, afterwards passing through the stone breaker *c*, into the bin below, and on through automatic feeders into the line of 30 heads of stamps, *d, d*, which discharge their pulp into the grinding pans, *e, e*, of which there are two to each 10 heads of stamps. The product of 10 stamps passes through two of the special grinding pans in succession, and is then conveyed by a suitable pipe to the first of a series of ten amalgamating pans, *f, f*, through which it passes in succession, and on into the line of four settlers, *g, g*, from which the tailings flow to the Frue vanners, *h, h*. On these the sulphides are concentrated, and any globules of amalgam which may have escaped the settlers are caught, so that when the tailings leave the mill they are practically sterile. With some ores the concentrators are not required.

The pans are heated indirectly through their hollow bottoms by means of the exhaust steam from the engine, *m*, which is supplied from the boilers, *l*.

The quicksilver is charged into the pans by means of pipes from the distributing tank, and the amalgam flows through suitably arranged pipes to the strainer, the mercury being returned to the tank by means of an elevator, *j*. The amalgam is retorted in the furnace, *k*, and the bullion melted into ingots.

The chemicals are supplied by means of two chemical feeders, and steam syphons are used for cleaning out the pans and for carrying the pulp past any one of them which it is necessary to cut out for repairs. The main line of shafting runs directly under the pans and settlers, each of which is driven from it by means of a friction clutch. This arrangement of separate clutches for each pan and settler is very convenient, as any number, or any one pan or settler, can be stopped in case of accident, or for cleaning purposes, without having to stop the whole line.

The whole of the water from the battery must pass through all the pans, so that even the finest slimes are subject to the amalgamating action, and no settling tanks or agitators are required.

CHAPTER XXI.

THE MILLING OF SILVER ORES (continued).

Dry Crushing Silver Mill—Specification of 10-Stamp Mill—The Leaching or Lixiviation Process—Roasting—Lixiviation—Description of Mill—The Leaching Vat—The Precipitation Vat—Acid Pumps—Quicksilver Elevator—Belt Elevator—Chain Elevator—Waterwheel Elevator.

DRY CRUSHING SILVER MILL.—A modification of the silver mill is necessary when the ore contains a large proportion of sulphides, and can no longer be treated by the wet crushing process. The arrangements for a dry crushing silver mill of the modern type are shown in section in fig. 226, and plan in fig. 227. The main alterations consists of drying and roasting the ore before amalgamation, the latter process being identical with that used in a wet crushing mill. The operation of roasting is described on page 421, and is identical with the same process required for the treatment of refractory gold ores before chlorination, except that salt is employed in order to convert the silver compound into chloride of silver in the furnace.

The ore from the mine is elevated to the top of the mill by means of the hoist, *a*, or may arrive direct along the platform, *b*. It is then tipped over the grizzly, *c*, and crushed in the breaker, *d*, whence it falls into the bin, *e*, and is fed by the automatic feeder, *f*, into the revolving dryer, *g*, and, after being deprived of all its moisture, passes on through the chute, *h*, into the feeder, *i*, and so to the dry crushing stamps, *j*, of which there are twenty, arranged on the line, *j j*, of the plan. After pulverisation, the ore is elevated and conveyed by the screw conveyers in the troughs, *l l*, to the chimney end, *m*, of the revolving roasting furnace, *m n*. In the furnace the ore is desulphurised and chloridised and is so

FIG. 226.—LONGITUDINAL SECTION OF 20-STAMP DRY CRUSHING SILVER MILL.

prepared for the pans and settlers. Leaving the roasting furnace

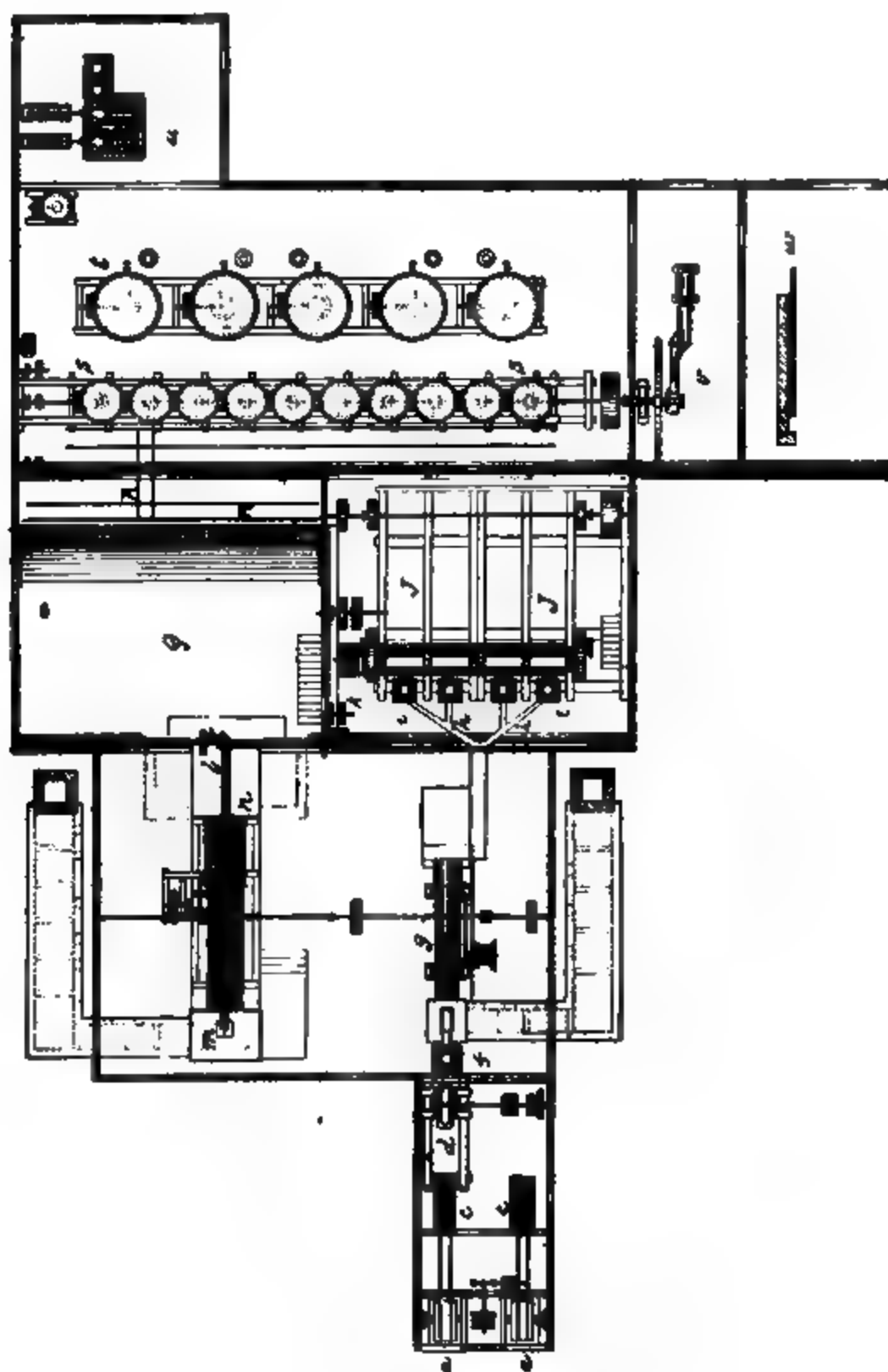


FIG. 227.—GROUND PLAN OF 20-STAMP DRY CRUSHING SILVER MILL.

—which may be one of the well-known types, some of which are described in Chapter XXIII.—the ore is spread upon the cooling

floor, *Q*, and is afterwards charged into waggons running on the rails, *R R*, and shovelled into the amalgamating pans, *S S*, of which there are ten, and afterwards the pulp is treated in one or other of the five settlers, *t t*; the amalgamation and subsequent operations are similar to those described for the wet crushing process. The mill is driven by the engine, *v*, and the boilers, *w*. The amalgam is retorted, and the bullion melted in the retort house, *w*. Instead of the amalgamation, the lixiviation process could be used with some classes of ore.

The power required for a 10-stamp dry crushing silver mill, such as that just described, and as specified in the detailed specification given below, would be :—

1 Blake rock breaker, No. 2	,	.	.	.	6 horse-power.
2 ore feeders	.	.	.	.	0 „
10 stamps, 750 lb., 90 drops	.	.	.	.	12 „
1 Howell-White furnace, 40 in.	.	.	.	.	4 „
4 amalgamating pans, 5 ft. diameter	.	.	.	.	8 „
2 settlers, 8 ft. diameter	.	.	.	.	6 „
Friction	.	.	.	.	9 „
<hr/>					
Total	.	.	.	.	45 „

The water required for the boilers, pans, and settlers would be somewhat less than 1000 gallons per hour.

SPECIFICATIONS FOR 10-STAMP DRY CRUSHING CHLORIDISING SILVER MILL (STEAM POWER).

Boilers :—

- 2 Fraser and Chalmers' tubular steam boilers, each 48 in. diameter × 14 ft. long, all complete as per specifications attached.
 - 1 Fraser and Chalmers' Corliss steam engine, size 14 × 42 in., all complete in detail as per specifications attached. Crank shaft to be fitted with suitable size clutch coupling for coupling to pan line shaft.
 - 1 Fraser and Chalmers' tubular steam heater, 24 in. diameter, all complete in every respect.
 - 1 No. 4 Knowles' boiler feed pump for feeding boilers with water.
- All necessary steam, exhaust, and feed pipes to properly connect boilers, engine, heater, and feed pump.

Grizzly :—

- 1 grizzly or ore screen for relieving crusher, size 4 × 10 ft., made from 2 × 1 in. iron with washers between. Rods to connect bars, with nuts for same.

Crusher :—

- 1 10 × 7 Blake crusher, all complete ready to run when set in place.

Automatic Feeders :—

- 2 Tulloch automatic ore feeders for stamps, with wood frames and sheet-iron hoppers.

All necessary track iron, punched and countersunk, with wood screws for laying same for feeders to operate upon.

Stamps :—

- 1 10-stamp mill of improved design, each stamp weighing 900 lb., arranged to run in one battery of 10 stamps by belt and tightener from stamp counter shaft, all complete in detail as below.
- 2 high mortars, double discharge, planed upon bottom and faced for screen frames. Foundation bolt holes drilled by template.
- 4 wood screen frames, fitted to mortars.
- 8 wrought-iron keys for holding screen frames in place.
- 4 brass wire cloth screens of such size as may be required.
- 10 patent stamp shoes.
- 10 patent stamp dies.
- 10 stamp heads, bored for stems and recessed for shoe stem.
- 10 stamp stems, made from extra refined iron, both ends tapered ; ends being tapered, when one end breaks the stem can be reversed and other end used.
- 10 tappets with wrought-iron gibs and steel keys, all properly fitted to place, faces turned.
- 10 cams (one-half right and one-half left hand), fitted to cam shaft with steel keys all properly marked to place to give proper drop.
- 1 heavy hammered iron cam shaft, turned full length and key-seated for pulley and cams.
- 2 wrought-iron collars with steel set screws, fitted to cam shaft.
- 3 heavy corner cam shaft boxes, babbitted and bored, planed upon back and bottom and furnished with bolts and caps. Boxes to be babbitted with best composition metal.
- 2 jack shafts, not turned.
- 4 jack shaft boxes.
- 10 iron sockets for wood levers, lined with leather.
- 10 wood levers or finger pieces for holding up stamps, fitted to sockets.
- 1 pair of double sleeve flanges for wood pulley, turned and fitted together with woodwork built up between, hubs key-seated, woodwork turned up, painted, and securely bolted through flanges.
- All necessary bolts, rods, nuts, and washers for 10 stamp, framework complete, including all holding down bolts and washers for mortars.
- 1 complete set of hard wood guide boxes for 10 stamps, all worked out for stamp stems, with all guide bolts, nuts, and washers.
- 4 sheets of rubber packing, each $\frac{1}{4}$ in. thick, for top of mortar blocks for mortars to rest upon.

Roasting Furnace :—

- 1 improved Howell-White roasting furnace, 52 in. diameter at small end, 62 in. diameter at large end × 27 ft. long, made in 8 sections, $\frac{3}{4}$ in. thick, sections faced and bolted together with $\frac{3}{4}$ in.-bolts, with all fixtures and fittings necessary to make the furnace complete in every respect as usually furnished, including carrying rollers, gearing, pulleys, vertical shafting, fire front, grate bars, etc.
- 1 smoke stack, 42 in. diameter × 60 ft. long.
- 400 ft. $\frac{3}{4}$ -in. guy rope.
- 1 base plate for stack.
- 1 set of fire tools for the above furnace.

Revolving Dryer :—

- 1 revolving dryer made of cast iron, 44 in. diameter at large end, 36 $\frac{1}{2}$ in. diameter at small end × 18 ft. long, made in sections, all properly turned and faced, drilled and bolted together with $\frac{3}{4}$ -in. bolts; dryer to be furnished complete with fire front, grate bars, bearings, binding bars, tie rods, gearing, boxes, truck wheels, sole plates for bearings, countershafts, tight and loose pulleys, and everything necessary to make dryer complete in all respects.
- 1 smoke stack for dryer, 24 in. diameter × 50 ft. long.
- 300 feet of $\frac{3}{4}$ -in. galvanised-iron guy rope.
- 1 cast-iron base plate for smoke stack.

Feeder for Dryer :—

- 1 Tulloch ore feeder for feeding dryer from ore bins, to be furnished complete with countershaft and pulleys.
- All necessary track iron, punched and countersunk, with wood screws for laying same for feeder to operate upon.

Sheet Iron Chute :—

- 1 sheet iron chute from dryer to self-feeders at stamps.

Pans :—

- 4 improved combination amalgamating pans, each 5 ft. diameter, with wood staves, to be furnished with upright cone in bottom upright spindle, fitted with separate steel toe, 2 hand wheels and screw on top of spindle for raising Muller nut for screw driver sleeves, driver arms separate from sleeves and bolted to same, Muller plate, 8 cast-iron shoes and 8 cast-iron dies to each pan, wrought-iron bands and lugs for staves, step box fitted on plate, which also carries one bearing of countershaft; step box to be fitted with steel buttons and bushings, countershaft, driving pulley, out end bearing for shaft, all bolts for boxes and for bolting to frame-work.

Settlers :—

- 2 8-ft. improved combination settlers with wood staves, to be complete in every respect as pans above, the enumeration being the same excepting shoes and dies, wooden shoes, and dies being furnished for the settlers.

Clean-up Pan :—

- 1 30-in. clean-up pan, with iron sides, complete in every respect. Fitted with cone pulley for changing speed.

Ore Bin Gate :—

- 1 ore gate complete for ore bins, with rack, hand wheel, slide, and plate.

Ore Gate for Dryer Pit :—

- 1 ore gate complete for dryer pit, with rack, hand wheel, slide, and plate.

Retort :—

- 1 14-in. silver retort complete, including cover, bar, and nut, screw for holding cover in place, 3 retort carriers, fire fronts complete, with doors and liners, dead plate, back bearers, 2 double grate bars, condensing pipe, cast-iron ashpan, wall binders and rods for bracing brickwork, and all necessary fittings required for the complete erection.

Bullion Furnace :—

- 1 set of castings for 16-in. bullion furnace top, including cover, bearing bars, grate bars, anchor bolts, and all fixtures and fittings belonging thereto.
- 6 assorted black lead crucibles and covers.
- 1 set of trays or cups, for holding amalgam.
- 1 pair of crucible tongs.
- 2 1000-oz. bullion moulds.
- 1 500-oz. bullion mould.
- 1 set of steel numbers for stamping bullion bars.
- 1 smoke stack for retort bullion furnace, 20 in. diameter \times 30 ft. long, with base plate and guy ropes for staying same.
- 1 set of iron floor plates for retort room floor, with all necessary screws for laying same.

Overhead Crawls :—

- 3 overhead carriage crawls complete.

Pulley Blocks :—

- 2 2-ton (Yale and Towne) differential pulley blocks, with endless chain.
- 1 1-ton (Yale and Towne) differential pulley block, with endless chain.
- 160 feet $1\frac{1}{2} \times \frac{1}{2}$ in. track iron, punched and countersunk, with wood screws for laying same.

Battery Conveyers :—

- 2 battery conveyers with 8 in.-flights, each conveyer 16 ft. long, to be furnished complete, with shafts, pulleys, pillow blocks, and collars.

Roaster Conveyers :—

- 3 roaster conveyers with 10-in. flights, each conveyer 16 ft. long, to be furnished complete with pulley, chain wheels, and bearings.

QUICKSILVER SYSTEM.

Elevator :—

- 1 complete quicksilver elevator, with rubber belts, Russia iron cups, and all fixtures and fittings required for making elevator complete in every respect.
- 1 each upper and lower quicksilver tanks.
- 2 quicksilver charging pots for pans, size 12 × 12 in.
- 2 amalgam safes with strainers complete, with padlocks and duplicate keys, with all necessary fittings and fixtures to make same complete.
- 1 amalgam car, complete.
- 120 ft. half-round track iron, with spikes for laying same for car to operate upon.

Quicksilver Piping :—

All pipes, iron cocks and fittings for the complete quicksilver circulation system that may be required in accordance with our drawings and necessary to make system complete in every detail.

Tighteners :—

- 1 main tightener for 16-in. belt, to be furnished complete with pulley, boxes, screws, hand wheel, nuts, and frames.
- 4 pan tighteners for 12-in. belt, with improved angle iron frames, shafts, pulleys, wrought-iron yokes, chains, upright shafts, step and guide boxes, hand wheels, and plates.
- 1 crusher tightener for 7-in. belt, with pulley, boxes, shaft, step, pinion ratchet, plate, dog and hand wheel, rack, wood frame, and bolts.

Dust Pipes :—

- 1 complete set of galvanised-iron dust pipes for removing dust from battery.

Exhaust Fan :—

- 1 Sturtevant monogram exhaust fan of suitable size, with countershaft complete for above dust pipes.

Water Pipes :—

All water pipes, valves, and fittings necessary for the complete mill for supplying pans and settlers, with necessary steam and water, ready for receiving connection with main water supply.

MEMORANDUM.

Sufficient pipe for connecting with tank or mill supply is not included.

- 1 hot ore car, complete, made entirely of iron.
- 2 ½-ton scoup ore cars, with iron bodies, 18 in. gauge.
- 1 set of ironwork for transversal car, with axles and wheels.
- 180 feet of 12-lb. tee rail, with spikes and joints for laying same for cars to run upon.

All necessary bolts, rods, nuts, and washers for the complete framework of mill building in accordance with the drawings as usually furnished.

7 complete sets of ore gates for pulp bins, with levers, slides, and plates.

Elevators :—

1 ore elevator complete, comprising :—

1 shaft $2\frac{1}{8} \times 5$ ft.

2 pillow blocks $2\frac{1}{8}$ in.

2 pulleys $36 \times 8\frac{1}{2}$ in.

1 shaft $2\frac{7}{8}$ in. \times 2 ft. 6 in.

2 pillow blocks, $2\frac{7}{8}$ in.

1 pulley 16 in. \times $8\frac{1}{2}$ in.

All necessary collars, bolts, and steel set screws.

88 7-in. Duc's heavy elevator buckets.

176 bolts for attaching buckets to belt.

125 ft. 8 in. 5-ply endless rubber belt for elevator, belt punched with holes for attaching buckets.

Shafting, Pulleys, and Boxes :—

All necessary shafting, pulleys, boxes, and belting for driving all of the above described machinery in accordance with our drawings.

An assortment of copper rivets and burrs.

Total approximate weight, 265,000 lb.

ADDENDA.

Smoke Stacks :—

In the above estimates are included smoke stacks for both roasting furnace and revolving dryer. If, however, it is desired to build stacks of brick, omit the smoke stacks included. Brick stacks are only practicable in some localities, and it will be found that iron stacks such as are included are the cheapest, being much more easy to erect. Stacks rolled, punched, and shipped K. D., in crates when desired : usually shipped in rivetted sections of 20 ft.

Firebricks for Roasting Furnace :—

For lining the 60-in. Howell-White roasting furnace, 3,040 special shaped firebricks are required. Sometimes this firebrick can be purchased near the mines. If, however, it is desired to have this brick shipped with the machinery the following is the cost and weight :

3,040 special shaped firebricks, weight about 36,500 lb., cost about \$310, f.o.b. cars, Chicago.

For this amount of firebricks, about two barrels of fireclay would be required, each costing \$4. and weighing 500 lb. each.

This mill as covered by specifications is complete and automatic.

Patent sectional stamp guides are recommended instead of ordering guides as specified above.

THE LEACHING OR LIXIVIATION PROCESS.—This process effects for refractory silver ores what the chlorination, or the McArthur-Forrest process, does for similar gold ores, and consists in first roasting the ore with salt, in order to convert the silver into chloride of silver, and then dissolving the chloride in hyposulphite of soda, from which it is afterwards precipitated in the form of sulphide of silver by the addition of a solution of sulphide of lime or soda. The Russell process, which is a modification of this, consists chiefly in the addition of a certain proportion of sulphate of copper to the hyposulphite solution.

The leaching process can be applied to all ores adapted to roasting amalgamation, as well as to the more refractory ones, and has, indeed, some advantages over that operation, in that the cost of the necessary plant is less, as well as the power required. The chief objection to its use arises from the fact that the chemical reactions involved are often complicated, and liable to sudden disturbances, owing to slight changes in the character of the ore. Another difficulty exists in the small number of men available to take charge of such works, owing to the thorough chemical knowledge which is essential, combined with the practical experience and good judgment necessary in the manager of a mining undertaking.

The process was introduced into Mexico in 1868 by Mr. Ottokar Hofmann, and has since come into extensive use in America for the reduction of all classes of silver ores, except such as contain so much lead that they can be smelted direct, or those which, on account of the clayey nature of their gangue, do not permit of free filtration.

Roasting.—The ore is first crushed and stamped dry in the usual way, and is then roasted in any of the kilns or cylinders in ordinary use for gold or silver ores, with the addition of salt in order to convert the silver into silver chloride, as described on page 421. For the successful roasting a sufficient quantity of mineral sulphides should be present, in order that by their decomposition they may produce sulphuric acid, which, in its turn, acts upon the salt, and so liberates the chlorine gas necessary for the formation of chloride of silver. The base metals present in the ores are converted into oxides, chlorides, and sulphates. The

amount of salt required varies from 4 to 10 per cent., according to the nature of the ore. As in the amalgamation process, the roasting is the most important operation, and must be conducted with great care.

The salt is added either before the ore enters the furnace or afterwards, when the excess of sulphur has been driven off and the oxidising roasting begun.

Lixiviation.—When the ore has been properly roasted it is moistened with water, and shovelled into wooden tubs in charges of from 10 to 15 tons. These leaching tubs are described on page 397, and are provided with a central discharge around which a filter bottom is arranged in the form of a flat funnel. The filter cloth is kept in place by ropes driven into grooves around the discharge hole and the inner circumference of the vat near the filter bottom.

The vat is furthermore provided with an outlet under the filter bottom, and has a slight inclination towards this outlet. The charge of roasted ore in the vat is leached with water in order to remove the soluble salts of the base metals. The silver chloride is insoluble in water; but if the charge is too thick the water becomes so saturated with the chlorides of the other metals as to become a partial solvent of silver chloride. For this reason the charges should not be too heavy. The leaching with water is continued until the whole of the soluble chlorides are dissolved out, which may be tested by the addition of a few drops of calcium polysulphide to a test-tube full of the outflowing liquor. If no discoloration takes place the leaching may be stopped; but this cannot usually take place under a period varying from 4 to 10 hours, according to the nature of the ore under treatment.

After the removal of the soluble salts of the base metals, a stream of a dilute solution of hyposulphite of soda is allowed to enter on top of the ore, and this readily dissolves the chloride of silver. The outgoing solution is now conveyed into special precipitating tanks, and in these the silver is precipitated by the addition of calcium polysulphide. The form of tank used is shown in fig. 229, and the precipitation is hastened by the action of the revolving stirrers. The clear solution of sodium hyposulphite is now decanted off, and is ready for use again; and if the operation

FIG 258.—ELEVATION OF LIXIVIATION MILL, WITH HOFMANN'S ROASTING FURNACES.

is skilfully performed this solution can be used over and over again for years. As soon as a sufficient quantity of sulphide of silver has accumulated in the bottom of the precipitating tanks, it is drawn off and strained through properly arranged filters of cotton cloth. It is then charged into a reverberatory furnace, and, after roasting, is melted with lead in a cupelling furnace and refined.

The tailings are sluiced out from the leaching tanks, and fresh ore is then charged into them. The wear and tear of the lixiviation plant is insignificant, and the wood is prevented from decaying by the action of the base metal salts. The calcium polysulphide, which is used as a precipitate, can be manufactured on the works by boiling two parts of fresh lime with one part of pulverised sulphur in water for three or four hours, in deep iron tanks, into which steam is directly introduced. The consumption of sulphur varies from 2 lb. to 7 lb. per ton of ore, and that of the lime at about double the amount, according to the nature of the ore. These, and the salt, are the only chemicals used.

Lixiviation Mill.—The general arrangements of a lixiviation mill are shown in fig. 228. The ore is crushed, dried, stamped, and roasted, as in the case of dry silver milling; the pulverised and roasted ore is then charged into the leaching tanks, *a a*, where, after having been washed in order to remove the soluble compounds, it is leached by a stream of hyposulphite of soda stored in the tanks, *b b*. The silver in solution is then run off into the precipitating tanks, *c*, when, after its precipitation, the renovated sodium hyposulphite is decanted off into the vat and pumped back by means of the pump, *f*, into the tanks, *b b*. The waste sands are sluiced out of the leaching vats and leave the mill by means of the chutes, *g g*. The whole arrangement is practically automatic, and were it not for the unforeseen chemical reactions set up occasionally by the changing nature of the ores, might, with advantage, be used in preference to the amalgamation process.

Special Appliances.—The special appliances used in a lixiviation mill instead of amalgamating pans and settlers, are leaching vats, precipitating vats, and acid pumps.

The power required to drive the stamps, dryers and roasting

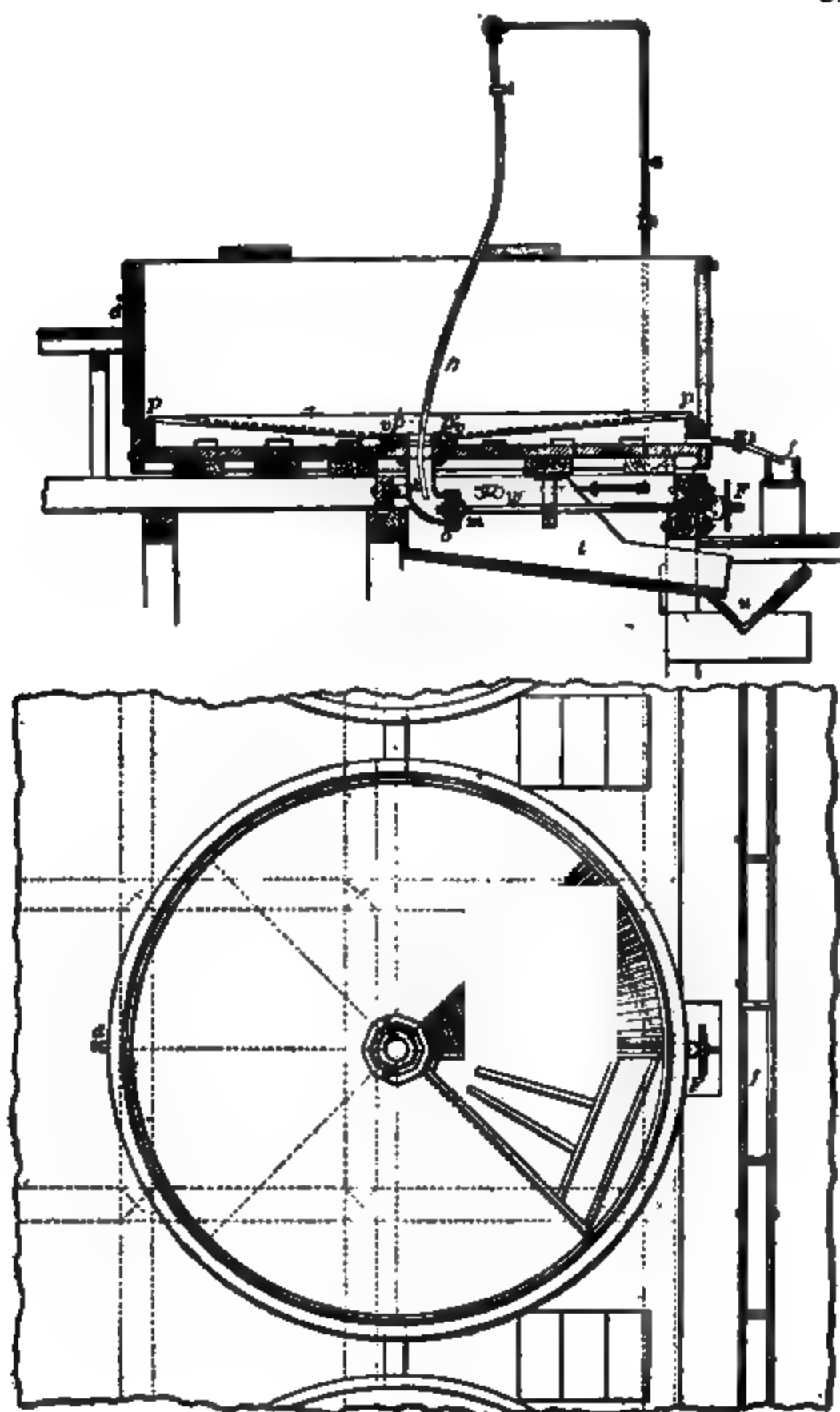


FIG. 229.—LEACHING VAT, WITH SLUICING ARRANGEMENT. PLAN AND SECTION.

furnaces as well as the amount of water necessary, will be found on page 387.

The Leaching Vat.—A vertical section and plan of this is given in fig. 229. The discharge opening is situated in the centre of the bottom, and is 6 in. in diameter. Beneath this, on the outside, the curved discharge tube, *k*, of the same diameter, is fixed. This tube is kept closed by the presence of the valve, *m*, and the screw, *f*, against the flange, *o*. The valve and the flange are of brass.

The wooden grating, *v*, slopes upwards from the discharge opening, *k*, and around the outer, *p*, and inner, *p*¹, circumference of this the circular grooves *p* and *p*¹ are formed, into which the filter cloth is wedged with rope. The slope of the grating, *v*, is $\frac{3}{4}$ in. to a foot. The air escape pipe, *d*, which reaches to the rim of the tank, enters the latter close under the filter bottom. It is provided with a tap for closing it when necessary. *z* is the water pipe; *n* is the central hose pipe, which reaches down to the discharge pipe, *k*, where it has to remain during the process of charging. This hose should be very stiff in order to prevent it from collapsing under the pressure of the contents of the vat. Before charging the tank, the discharge pipe is filled with water in order to prevent the inside of the hose from being blocked with ore.

When a tank is ready to be discharged, the wheel, *f*, is turned, and the valve, *m*, thus withdrawn. Water is now turned on through the central hose, which is moved up and down gently so as to undermine the tightly packed sand and cause it to fall in. Water is then turned on at the top, while the hose still at work prevents the blocking of the pipe, *k*. The sterile sands are carried away by the chute, *t*, into the sluice, *u*, which carries them out of the mill.

The silver solution is drawn off by means of the pipe and tap, *s*, and led by the trough, *f*, into the precipitating vat.

The Precipitation Vat, fig. 230, is provided with a wooden stirrer of the construction shown, driven by the gearing, *f*, at the rate of about thirty revolutions per minute if the diameter of the tank does not exceed 8 ft. or 9 ft. In order to break the violent motion of the current, the wings, *G*, which are about 3 in. wide, are

fixed inside the vat, and throw the solution back towards the centre.

The discharge pipe for the clear solution is shown at A in the

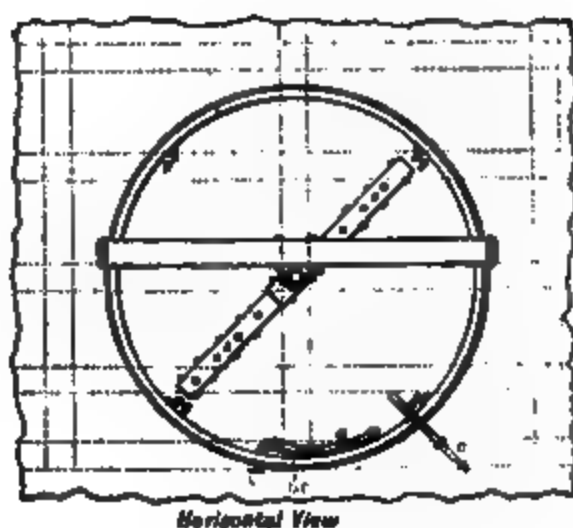


FIG 230.—PRECIPITATING VAT.

section, fig. 230, and also in the plan ; and B is that used for the precipitate. The branch pipe, C, reaches above the rim of the tank, and ends in a rubber hose, which is provided with a clamp. In precipitating, the stream of calcium sulphide can be

regulated, and the operator, by observing the colour produced by the precipitant in the moving liquor, can, after some practice, finish the operation quickly and more effectually than by the use of buckets.

One man can precipitate three tanks at a time; and owing to the thorough agitation of the liquid a perfect separation of the silver sulphide can be obtained; so much so, that the bottom of the tank can be distinctly seen through five feet of solution.

Acid Pumps.—The strongly acidulated waters required in the leaching process necessitates the use of an acid pump, such as that shown in fig. 231, which is built of hard rubber or copper—by preference the former—and fitted with a rubber plunger and valves. This class of pump is the best for the purpose, but is expensive when made entirely of rubber; so that where expense is an object, a pump made partly of hard white wood with hard rubber valves, bound together by copper straps and bolts, as shown in fig. 232, can be employed. Both pumps are driven by belting from the shafting of the mill.

Quicksilver Elevator.—The weight and fluidity of mercury both combine to make it a very difficult thing to handle without loss. Formerly it was the custom to carry it about the mill in buckets; and then, at a more recent date, and as indeed is now the practice in some mills, a system of pumps was erected by means of which the mercury was pumped back from the pans into a reservoir at the top of the mill, and thence distributed in pipes to the various appliances. The pumping of mercury, however, entails considerable difficulty in practice, and is now being superseded by the use of an elevator of much the same form as the ordinary belt elevator. The remainder of the pipe system is the same as when a pump was used, starting from the receiving tank at the top of the mill.

The elevator cups, B B, are made of Russia iron, and are of the peculiar shape shown in fig. 233, which is especially adapted for carrying quicksilver. The lower pulley, P, and bearings are carried by a cast-iron boot, to which, and extending up to and around the upper pulley, is attached a wooden, or, preferably, a sheet-iron casing, C, the joints of which must be made perfectly tight in order to avoid loss of any quicksilver spilled from the

cups. The upper tank, T, receives all the quicksilver, and like the lower is made of cast iron.

The distributing pipe, L, leads off from the bottom, and from

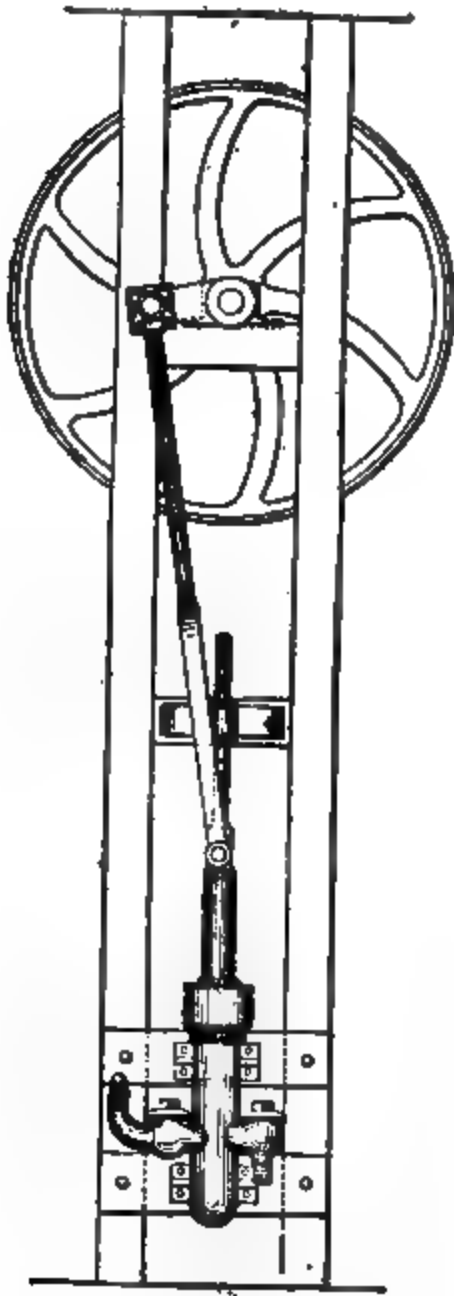


FIG. 231.—ACID PUMP OF HARD RUBBER, OR COPPER BARREL WITH RUBBER PLUNGER AND RUBBER VALVE.

FIG. 232.—ACID PUMP OF WOOD AND RUBBER.

this the other pipes branch off as may be required. The tank, M, shown in plan and section, is a receiving tank made of cast iron, in which the quicksilver returned from the mill is collected previous to being again elevated.

The amalgam in the pans and elsewhere in the mill is collected in lock-up sheet-iron safes of a portable form ; and in large mills sheet-iron cars running on rails are used. These, however, as well as the distilling and smelting furnaces, can hardly be classed as machinery, and the reader is referred to the books already mentioned for the details of distilling mercury, assaying ore, and smelting bullion.

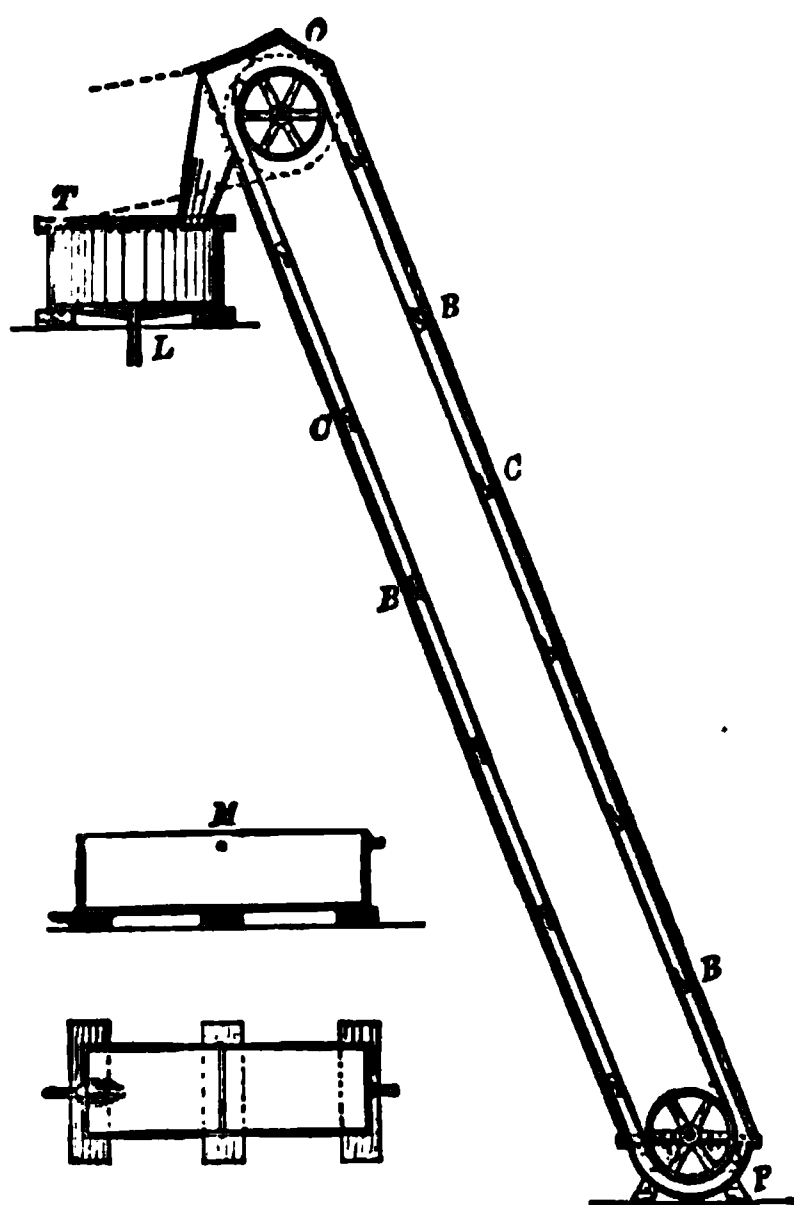


FIG. 233.—QUICKSILVER ELEVATOR.

ORE ELEVATORS.—*The Belt Elevator.*—In the designing and arranging of concentration mills of all types, the one great point to be kept in view is to make them automatic, so that the ore once fed into the crusher may afterwards pursue its way, by gravitation if possible, through the whole series of machinery.

For this purpose it is usual to build the mills on the slope of a mountain side, but even then it is not always possible to ensure absolute automaticity without calling some mechanical devices into

play. This almost invariably occurs in dry crushing silver mills ; and in order to convey the dry pulp from the stamps to the roasting furnaces, a belt elevator must be used in connection with screw conveyers. The belt elevator, shown in fig. 234, consists of a series of sheet-iron cups, attached at regular intervals to an endless belt passing over pulleys. The crushed and dried pulp from the battery is conveyed into the boot of the elevator by means of screw conveyers and is then lifted as fast as it is delivered

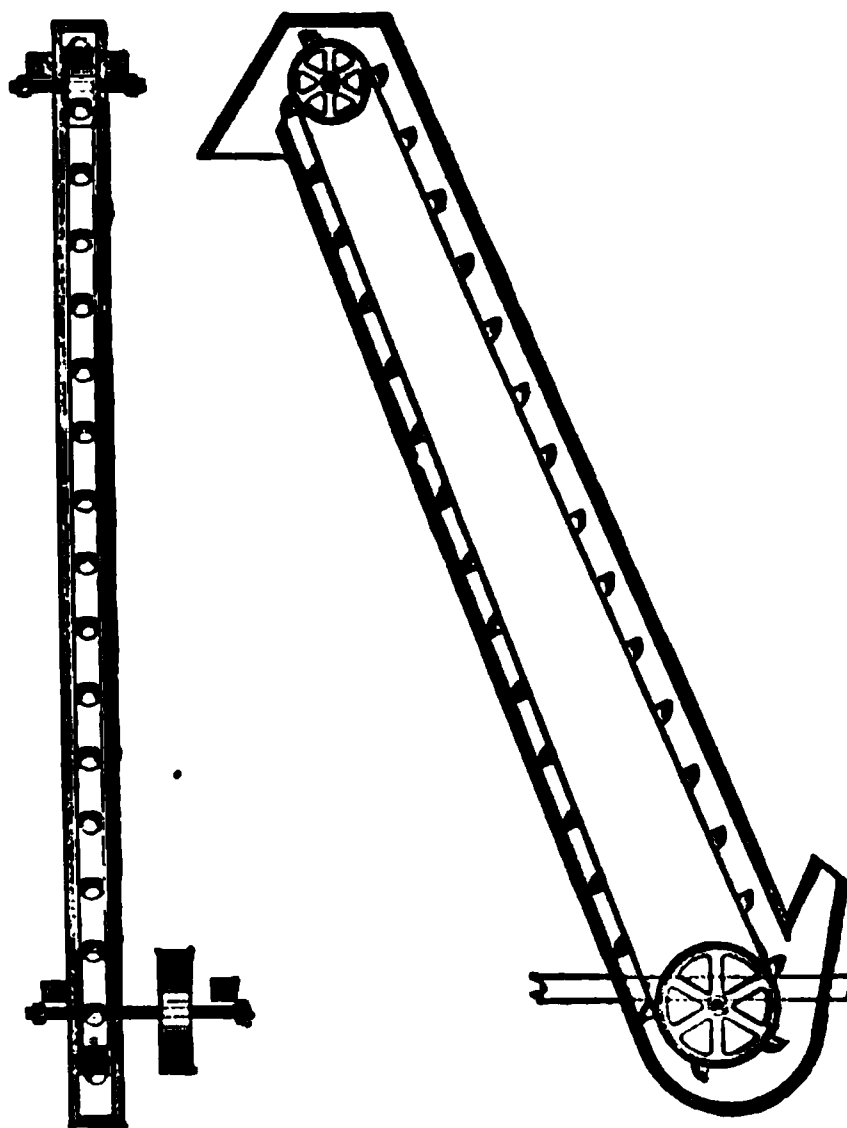


FIG. 234.—THE BELT ELEVATOR.

to the hoppers overhead, from which it either falls direct, or is again conveyed into the hopper of the roasting furnace. The elevator and conveyers must be surrounded by a wooden casing to prevent the escape of dust into the mill. The capacity of the elevator depends upon the number of buckets and the speed of the pulleys, and these are adjusted by the manufacturers to suit the quantity of ore and the height to which it has to be raised.

Chain Elevator.—The belt elevator just described is not

adapted for the lifting of wet pulp or slimes, and for this purpose either the buckets are attached to a chain, which for ordinary duty may be single; or, when for heavy work and wide buckets,

— ^{is} of two chains, placed side by side.

This form of elevator is shown in . 235, running at about 200 ft. per minute, but works best when placed at an angle instead of vertically. The chains work over chain wheels at each end. The shaft of the upper or lower wheel is arranged in adjustable bearings, and can be raised or lowered in order to keep the chains tight. Care should be taken that the shaft is kept quite level, and that each chain, if there are two, is equally tight, otherwise one or other will mount on the teeth of the chain wheels, and the driving shaft connected to the spur gearing, which is used to work the elevator, will be thrown off. If the chain elevator is too small for the work required of it, there will be much trouble in the mill and a display of power suited to the occasion. The elevator should have your elevator capable of doing double the work ordinarily required of it; and then, when any extra strain is thrown upon it, there will be no trouble from stoppages.

Iron Link Elevator. — For still heavier work the iron link elevator shown in fig. 236 is to be preferred. The arrangement is somewhat similar to the last, except that the buckets

FIG. 235.—CHAIN ELEVATOR.

are larger and are attached to wrought-iron links, running over a hexagonal drum at either end, the upper one being driven by gearing.

The links run in angle irons, by which they are supported when rising. I have found this form of elevator to work well in lead-

dressing mills for raising the coarse sands and tailings from the jiggers to the pulverising mills.

Waterwheel Elevator.—The best appliance for raising the fine slime waters to the height required for the fine concentrators is the waterwheel elevator, which is shown in plan in the section of a large lead mill, fig. 251, at N. The slime waters are collected in a pit under the wheel, which is revolved by gearing in the opposite way to the ordinary overshot waterwheel. The buckets

FIG. 236.—IRON LINK ELEVATOR.

dip into the slimes and raise them to the proper height, and then discharge them from the inside rim or back of the bucket into a receiving trough, which conveys them to the concentrators. The wheel is revolved slowly at a speed varying from two to three revolutions per minute.

The buckets should have a small hole in the bottom of each in order that the slimes may drain away when the mill is stopped, or otherwise, owing to their great weight it is somewhat difficult to restart the wheel, and the driving belt may be thrown off. If

this is not done then before the mill is stopped, the water supply should be cut off, so that the wheel may empty both itself and the pit below, and thus avoid difficulty in restarting.

I have had a long experience with one of these wheels and never had cause to complain of it, and for the raising of slime waters I much prefer it to all other forms of elevators.

CHAPTER XXII.

AMALGAMATING PLATES AND MACHINERY.

Copper Plates—Cleaning and Amalgamating the Plates—The Amalgamator—
 Conditions Necessary for Good Results—Losses in Amalgamation—
 Amalgamating Pans—Description of Pan—The Boss Standard Pan—
 The Wheeler Pan—Settlers—Agitators.

AMALGAMATING MACHINES.—When the gold occurs in a free state in the ore, it can be most advantageously extracted by means of the well-known apron of amalgamated copper plates, but when on the other hand the precious metal is closely associated with sulphides, the concentrates must be ground down to an impalpable powder in the presence of mercury, with which they are thus brought into intimate contact, so that the finest particles of free gold have every opportunity of becoming amalgamated and retained. The number of machines which have been invented, and in fact are being almost daily invented, for the purpose of the grinding and amalgamating of sulphides, is legion, and their description would require volumes. I purpose, therefore, only to notice a few of the better known appliances which have stood the test of practical work. There is, however, hardly a machine in use of which some good work cannot truthfully be recorded, especially when that particular machine is worked by a man who believes in its superiority, and the whole of whose care and intelligence are devoted to the obtaining of good results with it.

COPPER PLATES.—First, however, with regard to the apron of copper plates. The plates should be made of the purest and softest copper obtainable, and be perfectly free from dark or rough spots. The quality known as “braziers’ copper” is the

best material for the purpose. The width of the plates is that of the mortar box, while the total length employed is from 8 ft. to 12 ft., sometimes arranged in a series of shallow steps, and sometimes in one plain surface. The same width is kept for the full length, and the practice of narrowing towards the lower end should not be followed. The inclination at which they are set varies according to the different ores. Those with light gangues require but a slight inclination, while those containing heavy sulphides require one sufficient to prevent the settlement of sand on their surface. The weight of the copper should be about 3 lb. to the square foot for the exterior plates, but for those used inside the mortar box, a weight of from 6 lb. to 9 lb. per square foot should be used owing to the liability of the plates being torn or bent by the violent action of the ore in the box.

Copper sheets with the hard, shiny surface given by rolling after the last annealing, are not suitable, as they are not of sufficient porosity to take up the mercury. If these sheets only are procurable they must be annealed over a blacksmith's, or an open wood fire until thoroughly softened, in which state their capacity for absorbing mercury is greatly superior.

It is of great importance that the plates should have a true, even, and flat surface, and as the action of the mercury is to make them brittle, they must be blocked quite flat before amalgamation. To effect this they are laid on the true surface of a table, and flattened by the use of a block and hammer, the block being interposed between the hammer and the surface, so as to spread the blow over a large area, and so compress the copper into shape. The final flattening operation can best be conducted by screwing the plates down to a board, and when they have been beaten perfectly flat, the next operation is to thoroughly scour and clean one surface. The scouring is accomplished with a hard brush, and plenty of fine sand and water as well as a liberal allowance of elbow grease, which indeed must be the only form of grease allowed near the plates. All other must be removed by a scouring wash, with a solution of caustic soda or potash, and finally, after washing in clean water, they should be brushed over with a weak solution of cyanide of potassium.

This latter is a deadly poison even in weak solutions, and we

know of a case in which several bullocks were poisoned through drinking from a reservoir, into which the washings from the mill had been allowed to flow.

When the plates have thus been thoroughly cleaned and brightened, they are ready to be amalgamated. For this purpose they are coated with a mixture of fine sand, chloride of ammonium (sal-ammoniac), and a small quantity of quicksilver. This mixture is scrubbed over the plates with a brush until the whole surface is silvery bright, and the plate will not absorb more mercury. As several plates will be undergoing the process at the same time, the first is left to stand until the others have received their first coating.

No. 1 is then washed in clean water, again wiped over with a weak solution of cyanide, and more mercury rubbed over it until it will take up no more. The process is a long and tedious one, and, good as it is, the plates will not attain to their maximum efficiency as gold amalgamators, until after a fortnight's run. This is one of the causes why the first milling returns are always unsatisfactory and disappointing.

Many devices have been tried in order to get over this difficulty, as so to start the mill from the very first at its maximum efficiency. One of the best of these is by the use of copper plates, which after the preliminary cleaning have been coated with silver, either by the use of silver amalgam, or by electro-plating. These plates are doubtless more expensive, but when electro-plated to the extent of one ounce of silver per square foot, they are in a first-rate condition for receiving and absorbing the mercury, and will save their extra cost by the extra amount of gold which they will retain during the first week's run.

The duty of keeping the plates in working order devolves upon a skilled employé termed the "amalgamator"; and the following are the general conditions necessary to the successful amalgamation of the particles of gold, as they sweep over the plates in a constant stream from the stamps.

The conditions of a good result from amalgamation * are :—

1. Very fine stamping if the ore is fine.

* Eissler on "Metallurgy of Gold." Third edition. Crosby Lockwood and Son.

2. A coating of gold amalgam on the plates. No amalgam should be removed until a hard layer of it has been formed on the plates.

3. The use of a proper quantity of water. Too much will result in a coarse crushing, a less complete mechanical exposure of the fine gold, less contact of the gold and quicksilver, and a premature sweeping off of both. The addition of too much quicksilver, though causing the formation of more amalgam, will only lead to its being swept away by the current.

4. Proper temperature of the battery water. The water should neither be too hot nor too cold ; 90° to 110° Fahr. is the best, if by artificial means it can be raised to it.

5. The addition of quicksilver in proper quantity. This condition should be closely studied in each mill. There is always a considerable loss of quicksilver. The quicksilver introduced into the battery is finely divided by the stamps, and thus affords an opportunity for the amalgamation of the fine particles of gold. By the violent motion in the battery produced by the fall of the stamps, particles of gold, amalgam, and quicksilver, are carried away with the pulp to the copper plates to which they adhere.

6. Proper height of the charge in the mortar. This should not be allowed to rise higher than about 3 in. below the lower edge of the inner plates. If the quartz and pulp in the battery come nearer the plates, too much stuff, which is also too coarse, is thrown upon them thus either preventing the accumulation of amalgam, or displacing it after collection.

7. Regular feeding.

8. Care in keeping the plates clean.

9. Care in the mill against the introduction of grease or greasy substances, and against the use of exhaust steam for heating water required in any of the amalgamating processes. In lubricating the cam shaft, journals, cams, tappets, or any other portions round the batteries, care must be taken not to drop any lubricant into the mortar.

10. Rejection of hydrated oxidised iron ores silicate of magnesia and alumina ores. They cause a frothing of the water, and coat the gold with a slime which resists amalgamation.

11. Avoidance of mineral waters for battery amalgamation, especially if they contain sulphur in the shape of sulphuretted hydrogen, as a coating will be formed on the gold particles which prevents amalgamation.

12. Care that the amalgam on the copper plates is not allowed to get too hard, as it may fail to catch the gold. If, therefore, the amalgam should get too hard, it will be well to sprinkle some globules of mercury over it, through a chamois leather. If, however, it becomes too soft there is danger of flouting and losing it with some of the gold.

13. A dilute solution of cyanide of potassium should always be kept in hand, and when any yellow spots appear on the plate, some of the solution should be poured over it. If this does not remove the spot, hold a lump of cyanide over it or rub it, which will have the desired effect.

14. If the ores contain soluble sulphates, arising from the decomposition of iron or copper pyrites, the addition of lime will prove beneficial while passing through the battery.

15. When treating gold ores containing manganese, it is necessary to clean the plates of its adhering amalgam at least once a week, and give them a fresh coating of quicksilver.

16. It will be found that in many cases amalgamation can be promoted by discharging from the batteries on to concentrators direct, which will collect all the heavy mineral particles which interfere with the ordinary amalgamating process, and submitting the concentrates to separate treatment.

The overflow or tailings which pass the concentrators if carried over copper plates will now easily give up the gold, in case any fine particles have escaped in the concentrating process, as the ore has undergone a cleaning process by the separating of the sulphides in the concentrates, which naturally interfere with copper-plate amalgamation.

If the concentrates are submitted to treatment in grinding pans the tailings from the settler ought to be run over slime tables to collect any escaping particles of value.

When treating heavy pyritic ore, it will be found of advantage to have an iron pipe with little holes discharging a fine gentle shower of water on the copper plates, so as to assist the carrying

off of the heavy sulphides, which would cover the plates over, and prevent the contact of the free gold with the quicksilver.

The process of amalgamation by means of copper plates is, of course, not a perfect one, and the amount of gold which can thus be recovered will vary between 60 and 70 per cent. of the total amount contained in the gangue. This inefficiency and loss is due to various reasons which may be briefly summarised as follows :—

Losses due to the nature of the gangue, which, if it is clayey or talcose, is apt to coat the liberated particles of gold with a greasy slime which prevents their contact with the mercury. Gangues containing sulphides, which also prevent the amalgamating action of the mercury. In some cases also the surface of the gold has become oxidised or rusty, and here also the mercury cannot attack it. Various losses are also due to the action of the stamps in flattening the gold and driving particles of gangue into it, dividing it up into such minute particles that it floats away on the surface of the water. Again, the ore is insufficiently crushed, molecules of sand are left adhering to the atoms of gold, thus raising its specific gravity, and preventing its contact with the quicksilver. The quantity of water supplied will also cause the percentage of gold to vary. If too little is allowed the plates become coated with sand ; if too much, on the other hand, the gold is swept across them. The glorious mean is the point to be aimed at, and can only be attained by close attention and unceasing watchfulness on the part of the head man in the mill.

AMALGAMATING PANS.—The heavy concentrates from the blankets and other concentrators of some gold mills are ground up fine together with quicksilver in amalgamating pans, with a view to extract any free gold that may have escaped the action of the plates. The process of grinding in pans is, however, more adapted to silver than gold milling, and is described under the head of silver milling, the object being to reduce the pulp to an impalpable powder, and at the same time to mix it up with, and subject it to, the amalgamating action of mercury. With this end in view a large number of inventions have been brought out, the

general object being to produce grinding surfaces of the most effective form, securing the greatest uniformity of wear with economy of power ; to obtain the most favourable conditions for amalgamation, depending mainly on the free circulation of the pulp, the uniform and thorough distribution of the quicksilver, and the proper degree of heat ; and to combine with these requirements simplicity and cheapness of construction, facility in management and repair, large capacity, and economy of time, labour, and materials in the performance of duty.

The most approved form of pan is that with a cast-iron bottom and wooden sides, as shown in fig. 218, p. 376. The diameter inside the staves is 5 ft., which, however, may vary a few inches.

The bottom of the pan is mostly protected by cast-iron dies, *a*, fig. 218, p. 376, and the muller, *b*, is furnished with adjustable shoes, so that if it is necessary to grind the ore the wearing surfaces may be renewed. The muller is always adjustable by means of the hand wheel, and screws of top of the spindle, *c*, so that the shoes and dies can be brought together when grinding, or be parted for circulation and mixing only. The spindle, *c*, is provided with a renewable steel toe which is ground to a perfect fit and tempered. The step box, *d*, is bushed with brass, and loose tempered steel buttons are provided with the step box for the spindle toe to rest upon.

The mullers, *b*, are of various designs calculated to promote the most rapid circulation and intermixture of the pulp, one of which is shown in fig. 219. In some districts copper plates are introduced into the pan, and much of the amalgam is found attached to these, but the most usual system is to employ settlers entirely for the collection of the quicksilver and amalgam after the pans are discharged, which is effected through the pipe, *e*. Generally one settler is used for each two pans.

While the pulp is being worked in the pans steam is introduced to heat the mass and promote chemical reactions. Sometimes a steam bottom is used, as in the Boss standard pan, fig. 237. In other cases it is introduced direct into the pulp. The steam enters by the pipes, *a a*, and circulates in the chamber, *b b*.

The pans are driven by means of gearing and belting, as shown, but in the most modern mills, as in fig. 223, they are mounted

direct over the main engine shaft, to which they are connected by means of friction wheels.

FIG. 237.—THE BOSS STANDARD AMALGAMATING PAN.

In the Boss standard pan, fig. 237, projecting ledges are fixed to the inner side of the pan, which break up the pulp current as it swirls around, and force it towards the centre again

Another well-known type of pan is the Wheeler, shown in fig. 238, which is about 4 ft. in diameter at the bottom, and 2 ft. or a little more in depth.

A is the rim of the pan, in the centre of which is the hollow cone, B, rising from the bottom, with which it is cast in one piece. Through this cone the vertical shaft, C, passes, which being driven by the gearing below the pan gives motion to the muller, D, by means of the driver, E, which is keyed to the shaft, C. The muller is provided on the under side with shoes, G, that form the upper grinding surface. The form of the shoes is shown in fig. 239. They are attached to the muller by means of two lugs or projections, *ff*, which are received in corresponding apertures in the Muller plate, and securely wedged with pieces of wood. The lower grinding surface is formed by the dies, I, which are usually four or eight in number, covering the greater portion of the pan bottom, and secured to it in a manner similar to that by which the shoes are fixed to the muller. There is a radial slot or space between the dies, which is commonly filled with hard wood. Below the bottom is a steam chamber for heating the pulp.

FIG. 238.—THE WHEELER
AMALGAMATING PAN.

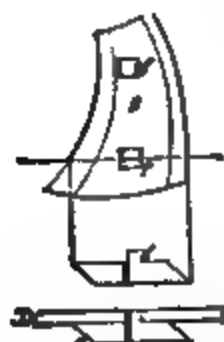


FIG. 239.—
SHOE FOR THE
WHEELER PAN.

The vertical shaft or spindle, *c*, rests in a step box, *h*, to which oil is conveyed by the pipe, *p*. A vertical pin passes downward through the centre of the step box, in contact with the shaft, and resting its lower end on the lever, *j*. This lever may be raised or lowered slightly by the hand wheel, *k*, thus raising the muller from the dies if required. The shaft, *c*, is also furnished with a screw, by means of which the muller may be raised up entirely above the rim

of the pan for the purpose of cleaning up or changing the shoes and dies. The hoisting apparatus required in the absence of this screw is thus avoided.

In order to give an upward current or movement to the pulp there are inclined ledges, *l*, on the rim of the pan, and smaller ledges, *m*, on the periphery of the muller, but inclined in the opposite direction. The pan is also provided with rings or guide plates, *n*, four in number, which serve to direct the moving pulp toward the centre. They are fitted into, and may be removed at pleasure from a T-shaped projection on the rim of the pan. The muller usually revolves at a speed of 60 revolutions per minute, and the pan requires from $2\frac{1}{2}$ to 3 horse-power. Its ordinary charge is from 800 to 1000 lb., but in some mills larger charges are worked; the treatment of a charge requires about four hours. The shoes and dies usually wear out in from four to six weeks. Mill men generally prefer a shoe of moderate rather than of excessive hardness. The former wear out faster, but are thought to grind more efficiently. They are usually cast of an equal mixture of white and soft iron.

The principal other pans are those known as Greeley's, Hepburn and Peterson's, Wheeler and Randall's, McCone's, the Combination pan, Fountain's pan, and Horn pan.

Settlers.—The pulp, after being ground and mixed with mercury in the amalgamating pan, is next led into settlers, in which it is thinned by the addition of water, and the quicksilver and amalgam is separated by settling from the sterile sand.

As with the pans there are numerous forms of settlers, but the most improved type is shown in fig. 220, p. 377. The pan is made of wood with a cast-iron bottom, and is of an inside diameter of 8 ft. A complete circular muller plate is attached to the upright spindle, and adjusted by the handwheels, as in the case of the pans. The muller plate is fitted with wooden shoes, and the whole weight of the muller and driver is carried by the upright driving spindle, which is supported in a step bearing on a steel button, the step bearing being mounted on a cast-iron plate resting on the cross timber of the pan framing. The weight of an 8-ft. settler, as shown, complete with staves and bands, is 7500 lb. Smaller sizes can be obtained.

Inside the staves around the bottom a groove is cast, starting from nothing on one side and gradually deepening to the syphon tap, *a*, on the opposite side, in which all the quicksilver is carried to the outlet. The pulp is drained off from the series of holes at successive intervals, the point of discharge being lowered by removing the plug from the next hole. There is no grinding action in the settler. All that is required is that the pulp shall be kept in gentle motion so as to allow the amalgam and quicksilver to settle. The muller revolves at the rate of about 15 revolutions per minute.

Agitators.—The pulp, as it leaves the settlers, may still contain

FIG. 240.—THE AGITATOR.

globules of amalgam or quicksilver, or the sulphides may be worth saving. In these cases it is usual to place an agitator, fig. 240, below the settler, so that any fine particles may be saved. The machine consists essentially of a wooden tub from 6 ft. to 12 ft. diameter and from 2 ft. to 6 ft. deep, in which the stirring arms, of which there are four, carrying vertical staves, slowly revolve. The stuff that accumulates at the bottom is shovelled out from time to time, and re-treated in one of the amalgamating pans.

Agitators, however, are not now generally used, and if there is any value left in the tailings, it is usual to put up more perfect concentrating appliances in order to recover it.

Clean-up Pans.—In these the amalgam from a gold and silver mill, when dirty and impure, is worked with additional quicksilver, and the waste matter washed off before retorting.

The Knox clean-up pan is 4 ft. diameter; wooden shoes are attached to the arms, and they are adjusted by means of the handwheels on top of the driving spindle, to bear on the bottom of the pan, or not, as desired, the motion being communicated through the bevel gear underneath to the spindle.

Fig. 221, p. 378, is a clean-up pan 3 ft. diameter, for the smaller silver and gold mills, wherein there are no wooden shoes; but a very heavy bottom and muller admit of the iron surfaces coming in contact, which is especially valuable in gold mills for working up small quantities of concentrates from blankets and sluices, when these particles need brightening or polishing, that they may be taken up by the quicksilver. Clean-up pans of both sizes are also made with removable grinding faces.

In fig. 221 a cone pulley (3-step pulley) is shown on the counter-shaft, which admits of varying the speed of the muller. These are supplied when desired.

1 4-ft. clean-up pan weighs	3000 lb.
1 3-ft. " " "	2000 lb.
1 30-in. " " "	1500 lb.

The best makers construct the whole of the various machines, pans, settlers, etc., in sections, suitable for transportation in mountainous districts on mule-back, the pieces being of a weight not exceeding 300 lb.

I am well aware that a great variety of machines have been invented for the purpose of amalgamation; but as most of them have not got beyond the experimental stage, and none have come into extended use, I have confined my description to the well-known and well-tried appliances which have given excellent results throughout the mining world.

Mercury.—As may be naturally expected, there is a considerable loss of mercury in all processes entailing amalgamation. With ordinary free milling ores the usual loss which may be expected is one-sixth of an ounce of mercury for each ton of ore milled. In a 10-stamp mill the loss of quicksilver per ton of ore will be from

one-sixth to one-third, or say 12 lb. to 15 lb. per month. The amalgam is retorted about once in every fifteen days, and the distilled mercury is returned to the battery again minus the loss mentioned above. In a 10-stamp mill it is advisable to have two tankards of mercury in reserve, one for use in the batteries and one for the amalgam pan. A mill of, say, 80 stamps, running an ore of a value of 30s. to £2 per ton (\$8 to \$10), only six tankards, or 460 lb., would be required in reserve. The ordinary amalgam pan requires about 200 lb. of mercury to run it properly. Fine gold requires a proportionately larger quantity of mercury for amalgamation than coarse, and the loss is a little greater. Greater losses occur on partly refractory ores, and the mercury must in all cases be handled with great care, or the losses will much exceed the estimate.

For a 10-stamp silver mill the stock of mercury should be large to begin with. In a dry crushing silver mill the loss is usually from $\frac{1}{2}$ lb. to $\frac{3}{4}$ lb. per ton of ore. Ten-stamp mills usually require from 200 to 250 lb. of mercury per month to make up for loss, or say three flasks. The stock which should be kept in hand will depend upon the richness of the ore, but would be about 1500 lb. in the pans, 1500 in the settlers and in circulation, and at times 1500 lb. locked up in amalgam, so that a stock of from two to three tons would be required to start with.

As a rule, in dry crushing silver mills, little or no chemicals are used in the pans, with the exception of occasional borings of iron or zinc, amounting to 8 lb. to 10 lb. per ton. The chemicals given in the list on page 363 would in most cases answer for a dry crushing silver mill also.

CHAPTER XXIII.

DRYING AND ROASTING MACHINERY.

Ore Drying and Roasting Machinery—Drying Floors—Drying Cylinders—Shelf Drying Kiln—Roasting—Reverberatory Furnace—Brückner Roasting Cylinder—Improved Brückner Cylinder—The Howell Improved White Cylinder—The Stetefeldt Roasting Furnace—The O'Hara Roasting and Chlorodising Furnace.

ORE-DRYING MACHINERY.—It is absolutely necessary that before the ore is sent to the stamps for dry crushing it shall be perfectly dry itself. The old method of drying the ore was to spread it upon a flooring of iron plates, underneath which there was a labyrinth of flues. This method, however, is not economical, and entails much handling of the ore. The modern method is to dry the ore in a revolving iron cylinder, such as that shown in fig. 241, and which, in the mill, is situated in the position shown at *g* in fig. 226, between the ore bin and the stamps. The cylinder is of cast-iron, made in several sections for convenience of handling, and having two tyres on which it rotates, supported by rollers underneath.

The rotating motion is transmitted to the cylinder through the spur-gearing and belting shown. The cylinder is slightly conical in shape, being as a rule 36 in. diameter at the smaller end, into which the ore is fed, 18 ft. long, and 44 in. diameter at the larger end nearest the furnace. Its total weight is about 19,000 lb., and its capacity from 30 to 40 tons per 24 hours.

The iron cylinder is lined with firebricks, for which purpose about 1100 are required, and it should be connected to a chimney of about 40 ft. high.

The axis of the cylinder is placed horizontally ; but, owing to

its conical form, the ore must travel gradually from the smaller towards the larger end, where the furnace is placed. Shelves or wings are arranged spirally inside the cylinder, and raise the ore and shower it through the flames, thus assisting to quickly and thoroughly dry it. The dried ore drops into a pit, from which it is drawn through a cast-iron door, and by means of sheet-iron chutes is conveyed to the automatic feeders and so on to the stamps.

The ore may also be dried on a "shelf dry kiln," which consists of a series of inclined iron shelves arranged in a kiln in such a fashion that the ore will slide downwards from one to another, being at the same time exposed to the action of the heated gases ascending from the furnace below. The process is economical, and requires no motive power and produces no dust.

Roasting.—Many of the ores of gold and silver contain the precious metals so securely locked up that they cannot be freed by the mechanical action of pulverisation for the succeeding processes of amalgamation, lixiviation, or chlorination. Chemical means must therefore be resorted to, and the operation usually adopted is to roast the ores in suitable kilns, furnaces, revolving roasting furnaces, with a view either to convert the metal in the ore to the state of oxide, called oxidising roasting, to the state of sulphate, or lastly, to that of a chloride, called chlorodising roasting, according to the ore and the treatment to be afterwards carried out for the recovery

FIG. 241.—REVOLVING ORE DRYER.

of the precious metals. The subject is a vast and intricate one, and necessitates considerable chemical knowledge for its successful manipulation, and I would refer my readers to the two treatises, of Mr. Eissler,* on the "Metallurgy of Gold" and the "Metallurgy of Silver" respectively, in which they will find full details of the practical working of many of the numerous roasting furnaces.

The ore is either roasted in the mass as it comes from the mines, in which case it is treated in heaps, stalls, or kilns, or after it has been crushed, with or without concentration, in the mill.

As we have now to deal more especially with the machinery employed to effect the operation, it is with the latter class of ore with which we have to deal, and must go back for a moment to the crushing or pulverising machinery. Now, the most suitable condition of the powdered ore or pulp for roasting is when the ore particles are finer than those of the gangue. When the crushing is accomplished by means of rollers, the grains or particles of ore and gangue are of a more even size, which, though of considerable advantage for concentration, is not so much so for roasting. The reverse, however, appears to be the case when the mineral has been stamped; for in stamping, owing to the greater specific gravity of the ore particles, they cannot so easily evade the blows of the stamp, and remain longer exposed to their action than the lighter gangue, and are consequently reduced to a finer state. The ore particles, therefore, are reduced to a finer grade than those of the gangue, and thus the mineral is in the most suitable condition for roasting.

The appliances used for the roasting operation may be either reverberatory furnaces and kilns built of brick, as in figs. 242, 243, or a variety of revolving roasting cylinders, or furnaces built on the Stetefeldt or O'Hara principles.

The furnace shown in fig. 242 is given for the sake of comparison with the mechanical roasters, and may be either single or double, as the one illustrated in the small chlorination mill, fig. 249.

* Crosby Lockwood and Son, London.

Reverberatory Furnace.—The small single furnace shown in plan and section in figs. 242 and 243 will treat one ton of sulphides at a charge upon the hearth-bottom, *a*. It is fed in through a hole

FIG. 242.—PLAN OF REVERBERATORY ROASTING FURNACE.

in the arched roof, *g*, and spread out in a thin layer upon the hearth, where it is exposed to the action of the heat and gases from the furnace, and at the end of the operation, during which



FIG. 243.—SECTION OF REVERBERATORY ROASTING FURNACE.

it is raked over and stirred by hand through the side openings, it is discharged through the square opening, *b*, in the floor into the pit, *c*, and is then removed to the cooling floors to await the next process. The bridge, *e*, is from 10 in. to 12 in. wide

and from 8 in. to 10 in. high, and should be made of some refractory material, like firebricks. It separates the hearth from

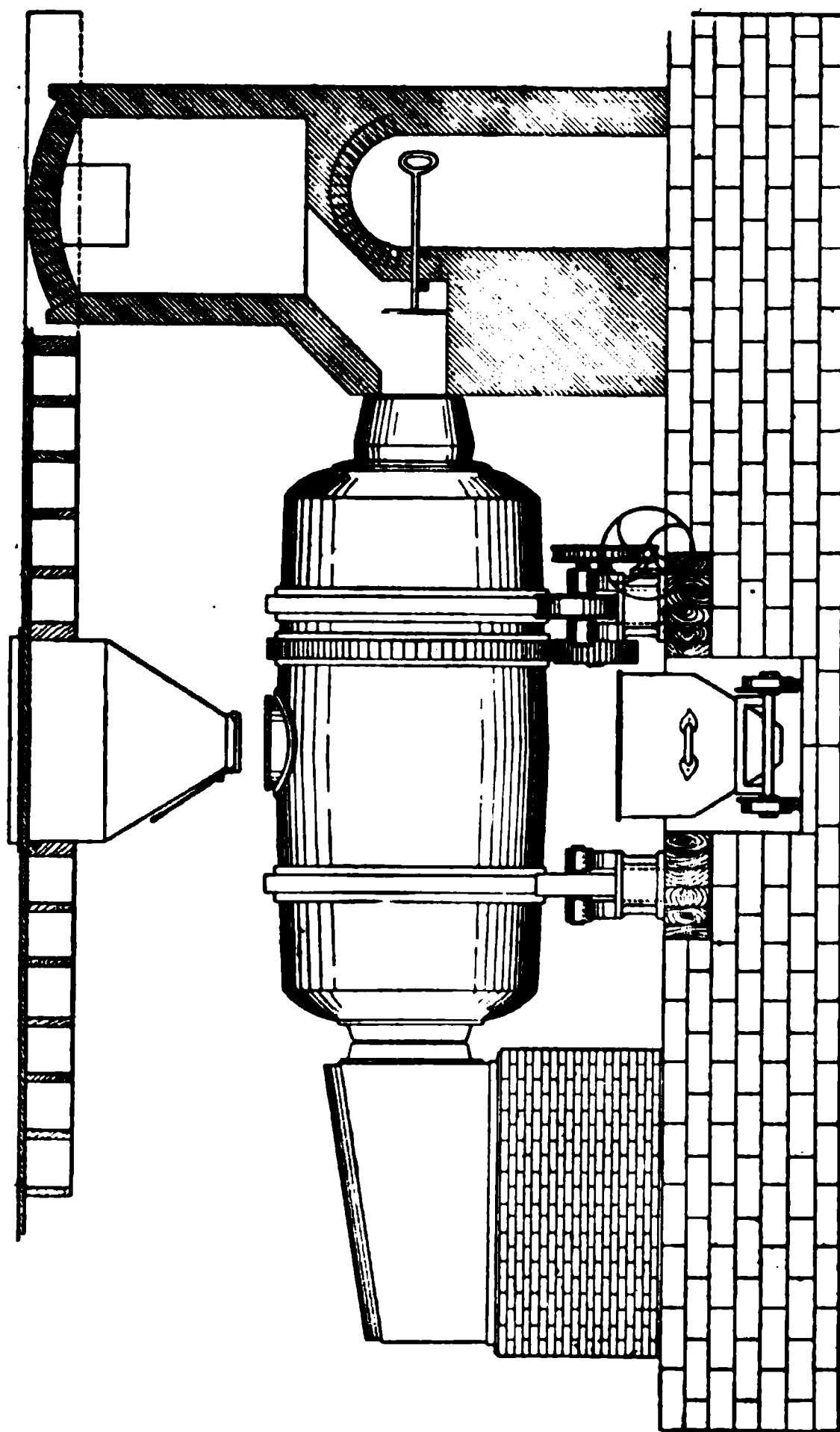


FIG. 244.—BRÜCKNER ROASTING CYLINDER.

the fireplace. The outside walls should not be less than 24 in. thick. The roof should not be more than 20 in. from the bottom, and the whole construction should be well braced together by

means of iron ties and wall-plates, *p*. The smoke and fumes pass away through the flues, *h* and *i*, into the chimney, on the top of which is a cover, *n*, by means of which the draught may be regulated.

Passing now to the mechanical arrangements by which roasting is accomplished in modern mills, of which indeed there are numerous varieties, we will notice a few only of those which have become most favourably known, and are generally adopted in gold and silver mills for the roasting of refractory ores.

The Brückner Roasting Cylinder, represented in fig. 244, is 6 ft. in diameter and 12 ft. long, revolves on four rollers, and is rotated by the spur gearing shown, which in turn is driven by the worm gear and pulley. The cylinder is of iron, lined throughout, both in the body and conical ends, with firebricks, of which a total number of 1300 will be required for this purpose, and for lining the iron firebox shown on the left. The hopper placed above the cylinder is sufficiently large to contain a charge which, for this machine, will be from 3 to 4 tons. Two receiving and discharging doors are provided midway in the length of the cylinder, and come directly under the hopper. They discharge into an iron hot ore car placed beneath, or, if desired, straight into the pit.

At one end is the furnace, and at the other the chimney. The conical ends revolve close against the openings, and the draught is regulated by means of the damper as shown.

The revolution of the cylinder causes the ore to be thrown backwards and forwards, and so, by changing its position, frequently exposes new surfaces and particles to the action of the fire.

The capacity largely depends upon the ores, some of which require but four or five hours to be thoroughly roasted and chlorodised, while others need as much as twelve hours, or longer.

The weight of the 12 ft. \times 6 ft. cylinder is 15,000 lb., and its capacity 3 to 4 tons. The larger size, 7 ft. \times 18 ft., capable of treating 6 to 8 tons at a batch, weighs 28,000 lb.

The Improved Brückner Roasting Cylinder, illustrated in fig. 245, is 7 ft. diameter \times 18 ft. long, made of the best iron, and lined throughout with firebricks. It revolves on two chilled iron

friction rings, resting on four chilled iron rollers. The rotation

FIG. 245.—IMPROVED BRUCKNER ROASTING CYLINDER.

is caused by friction on the carrying rollers, which are driven by spur-gearing and pulleys.

The cylinder is provided with four receiving and discharging

doors, in two pairs, placed opposite each other. The operation is the same as in the cylinder previously described, and the weight, with iron trimmings for the brickwork, is 30,000 lb. With an iron smoke stack, base plate, and guys added, the weight is 31,500 lbs.

The drawback to the Brückner cylinders just described is that they are not continuous in their action, but deliver the ore in batches at considerable intervals. To obviate this difficulty the *White* roasting furnace has been invented, and improved upon again in the *Howell Improved White Roasting Furnace*.

The Howell Improved White Roasting Furnace consists of a long cast-iron revolving cylinder inclined towards the fireplace, as shown in fig. 246, and enlarged at the lower end, which alone is lined with firebrick, leaving the metal on the smaller portion exposed, as the greatest heat is at the fire end. It is supported on four wheels or rings, resting on truck wheels, and guided in a central position by rollers in upright frames, and is revolved by friction on the truck wheels, which are driven by means of gearing and pulleys. Inside the cylinder the ore is raised, and showered through the flames by means of cast-iron spirally arranged shelves, which rotate with the cylinder.

The ore is fed through a hopper at the chimney end, and if

FIG. 246.—HOWELL IMPROVED WHITE ROASTING FURNACE, REGULAR PATTERN.

salt is used for chlorodising it, is mixed with it before it enters the cylinder. It then slowly finds its way down the cylinder from the coolest to the hottest end, and finally drops into a pit at the lower end, whence it can be withdrawn as roasted pulp as required.

These furnaces are built in three sizes—

40 in. x 24 ft.	.	.	.	capacity 15 to 20 tons.
52 „ x 27 „	.	.	.	„ 20 „ 30 „
60 „ x 27 „	.	.	.	„ 30 „ 45 „

The amount of firebrick required for lining the furnaces and 20 ft. of dust chamber is—

Size of Cylinder.	No. of Common Bricks.	Firebricks.
40 in. x 24 ft.	26,000	1,900
52 „ x 27 „	26,000	1,900
60 „ x 27 „	28,000	2,700

Auxiliary furnaces for roasting the dust, which escapes from the main furnace, are sometimes used for both the White and the Howell improved White roasting furnaces, but are now seldom employed.

The Stetefeldt Roasting Furnace.—In this furnace the ore is chlorodised and roasted while falling from the hopper, A, of fig. 247, down the shaft, B, which is from 26 ft. to 46 ft. high, according to the refractory nature of the ore. The shaft, B, has a horizontal section of from 4 ft. to 6 ft. square, and is heated by the two fireplaces, G. In order to obtain perfect combustion of the gases when leaving the furnaces, they are supplied by means of the passages, or with a current of fresh air, regulated by dampers, to the quantity necessary to obtain a perfect combustion of the gases.

The main shaft is built slightly tapering and is double, so that the air space between may keep the heat regular; it is connected at the top with the flue, H, in which the fine dust, which is carried over in considerable quantities by the strong draught, receives an additional roasting from the fireplace provided at E, and is finally deposited in the hoppers, F F, of the dust chamber,

D. The water gases pass off through a chimney which is from 60 ft. to 100 ft. high and from 4 ft. to 5 ft. square.

The main body of the ore falls through the ascending current of gases in the shaft, B, into the hopper, C, from which it is with-

FIG. 247.—THE STETEFELDT ROASTING FURNACE.

drawn by special arrangements, while the various doors, R, and Q, serve to admit air, and for examining and cleaning the interior, and the dust which settles on the sloping sides of W can be removed by the doors, S S.

The Stetefeldt furnace is made in three sizes, of which

No 1 has a capacity of from 40 to 80 tons per 24 hours.

„ 2	„	„	20 „ 40	„	„
„ 3	„	„	10 „ 20	„	„

the capacity, however, varies much with the quality of the ore. The cost of roasting by this method is from 16s. to £1 per ton, though, in places where salt, fuel, and labour are expensive, it may run up to £1 16s. per ton.

The following is a list of the materials used in the construction of these furnaces :—

	Iron Plant.	Stone.	Bricks.	Firebrick.
No. 1	48,000 lb.	3,000 cu. ft.	260 M.	5,000
„ 2	32,000 „	2,500 „	200 „	3,500
„ 3	25,000 „	2,000 „	150 „	2,500

The O'Hara Roasting and Chlorodising Furnace.—We have now seen how the roasting furnace has been developed from the original reverberatory hearth to the automatic and continuous processes of the Brückner and Stetefeldt furnaces, and the last mechanical arrangement which will be described is that known as the O'Hara, which consists of two long separate hearths, one above the other, over which the ore is drawn in a steady stream, being desulphurised on the upper, and chloridised on its return journey across the lower, hearth. The whole arrangement is shown in fig. 248.

Attached to an endless chain, at proper distances apart, are iron frames formed into a triangular shape ; on these frames are a number of ploughs or hoes set at an angle. One set turn the ore toward the centre, the next set turn it in an opposite direction toward the walls. These ploughs move through the ore every minute and expose a new surface of ore to the flames and gases.

The space between the roof and hearth of each compartment is quite small, so as to confine the heat close to the ore.

The operation of this furnace is as follows :—The ore is fed continually from the battery into the hopper, through which it then falls on the upper hearth. The ploughs, actuated by the endless chain, stir the ore over and over on the hearth and move

it gradually to the opening, where it falls to the lower hearth. As the ore is passed along in the upper compartment it is

FIG. 248.—THE O'HARA ROASTING FURNACE.

thoroughly desulphurised by the heat furnished by the fires as described, and by the combustion of the sulphur in the ore.

This action is assisted by the oxygen in the supply as admitted at intervals through the sides of the furnace by the openings,—for a chloridising roasting salt is mixed with the ore as it is fed into the hopper, and becomes thoroughly intermingled with it by the stirring action of the ploughs. If there is any free silver in the ore it gets the benefit of the chlorine vapours passing up from the lower hearth.

When the ore falls through the opening and on to the lower hearth, the fall breaks any spongy lumps or masses that may have been formed, and the ore is again stirred over and over, and moved along through the flame and gases over the lower hearth by the action of the ploughs towards the discharge opening.

The ore has become gradually more and more heated in its passage through the upper hearth, and by the time the extra heat is required as stated it comes immediately in front of the same fires which have, during the whole process, furnished the heat.

Ordinarily the ore will be from five to ten hours in passing through the furnace—according to its character. Only one man is required to attend the fires, no other attention being necessary, as the ore may be fed to the furnace by mechanical means, and discharged from the furnace in a car, conveyer, or elevator, and discharged in hoppers over the pans.

The materials required for the construction of an O'Hara furnace are—

METAL.

Bolts	1,100 lb.
Wrought iron	6,600 „
Cast iron	3,125 „
<hr/>	
Total	10,825 lb.

BRICK AND STONE.

Furnace	137,000
Stack 80 ft. high, 7 ft. × 7 ft. base, 2 ft. × 2 ft. flue, built hollow walls	75,000
<hr/>	
Total	212,000

Stones, 125 cu. yds. ; firebricks, 100 cu. yds. or more ; length of

hearth, 60 ft. ; two cooling hearths, each 30 ft. = 60 ft., total 120 ft. ; width of hearth, 8 ft. ; ditto over all, 14 ft. ; height over all, 14ft. Will work up to 50 tons. Burns 3 to 3½ cords of wood per day. The top of the furnace may be covered with cast-iron plates, making a first-class drying floor. It is continuous in its working. A furnace of smaller dimensions for working 20 tons will cost somewhat less.

CHAPTER XXIV.

THE CHLORINATION AND CYANIDE PROCESSES FOR THE EXTRACTION OF GOLD.

General Outlines of the Chlorination Process—Description of Providence Mill, Colorado—The Newbery-Vautin Process—The Cyanide Process.

THE two processes by means of which gold is extracted from refractory ores are either by chlorination, or else by the use of cyanide of potassium.

THE CHLORINATION PROCESS.—This consists first in roasting the ore, as described on p. 421, and then in the conversion of the gold particles into terchloride of gold. The process may be described in general terms as follows :— *

(1) The auriferous concentrates from the stamping mill having been perfectly oxidised by roasting, are moistened with water and put lightly by means of a sieve into a wooden vat, coated with tar and rosin, and having a perforated false bottom, upon which a filter is made, for which there are numerous ways. When fitted, a close-fitting cover is placed on the top.

(2) Chlorine gas, produced by decomposing salt and peroxide of manganese with sulphuric acid, is introduced between the false and true bottoms, and made to permeate upwards through the ore mass. After the expiration of from fifteen to forty-eight hours, the gas is found to appear abundantly on the ore mass, and is then shut off, and the vat allowed to remain a few hours under the influence of the gas. The cover being removed, pure water is added to fill the vat even with the top surface of the ore. The

* "Treatise on the Concentration of all Kinds of Ore, including the Chlorination Process," by the late Professor Küstel. (San Francisco, 1868.)

fine particles of gold, under the action of chlorine, have changed from metal to a soluble terchloride, and in this condition it is drawn off or leached out with water, fresh water being added until a test shows no trace of gold.

(3) A prepared solution of sulphate of iron—the usual precipitant—is carefully added to this drawn-off solution, and the gold thrown down as a black or brownish precipitate. This is gathered, washed, and melted into ingots of nearly pure gold.

The conditions just mentioned are carried out in practice by a simple arrangement of vats (as shown in fig. 249, which illus-

trates the chlorination mill at the Providence Mine, Grass Valley District, Colorado), and the process is as follows:—

“The ore treated is quartz, carrying free gold, pyrites, galena, chalcoppyrite, arsenopyrite, and zinc blende. It is first crushed in rock breakers, and then stamped fine enough to pass through a 40-mesh sieve. Then it passes as a slime over silver-plated copper amalgamating plates to Frue concentrators. The free gold is caught in the stamp batteries and on the plates; the sulphides are collected by the concentrators. The latter are dried and then roasted, chlorinated, and leached. The roasting is done in a

three-story reverberatory furnace. About 1 per cent. of salt is added near the close of the operation. All the sulphur, arsenic, and antimony are expelled, and the iron and other base metals oxydised. The gold is left in a free metallic state, the silver being partly concentrated into a chloride by the salt.

"The roasted ore is then transferred to chlorinating tubs, holding from two to three tons each. The covers are put on, and the joint caulked with rags and luted with dough to make it gas-tight. The tubs have false bottoms, full of holes and covered with sacking. Chlorine gas, made from salt, black oxide of manganese, and sulphuric acid, is then introduced below the false bottom and allowed to permeate the ore. Two or three days are required for their permeation. The gold and silver is thus concentrated into chlorides. The chloride of gold is leached out by water added at the top and drawn off at the bottom, and run into precipitating tanks. The gold is precipitated in a fine metallic state by the addition of sulphate of iron. The water is then run off, the gold collected and dried, melted in graphite crucibles, and cast in bars.

"The silver chloride remaining in the ore is dissolved out by a solution of hyposulphite of soda. The solution is run into other tanks, and the silver precipitated as a sulphide by adding calcium polysulphide. The sulphide of silver is dried, roasted, and then melted and cast into bars. The cost of milling and treating the sulphides is \$1.37 per ton of ore."

The simplicity of the above arrangement involves, however, the handling of the ore several times, in order to fill and empty the vats.

The Newbery-Vautin Chlorination Process. — Many attempts have been made to improve upon the simple chlorination plant already described, and perhaps that known as the "Newbery-Vautin" is the one which hitherto has been the most successful from a commercial point of view, and has given most satisfactory results, notably at the Great Mount Morgan Mine in Queensland, Ballarat, Sandhurst Goldfields, and other places in different parts of the world.

The plant required for the chlorination of the ores after roasting, is simple in its construction, requires but little power, and its working will be understood by reference to fig. 250.

The processes already described having been gone through, the roasted ore—which should be crushed to such a state as to pass through a 30-mesh sieve—is delivered into the chlorinating mill by the truck, B, on the tramway, A, and discharged through the hopper, C, into the chlorinating barrel, E. Five to 10 per cent. of water is then added, with 1 per cent. of chloride of lime and the same quantity of a special new reagent; the cover is then secured and the chlorination set in motion, until the gold is transformed into chloride of gold and has been dissolved.

The solution of gold is then removed, either by upward or downward leaching—which can be effected by gravitation or the use of a pump—into the tank, H, and then from there by the pump, F, into the tank, I; or, in order to facilitate the leaching, the pipe connected with the chlorinator can be connected direct with the pump. Another method of filtration is by admitting water under pressure at the top of the chlorinator when closed, and forcing the solution through the filtering medium contained in the bottom of the vessel and into the tank, H, from which it can be pumped up into the tank, I.

The solution in the tank, I, which contains the gold in the state of chloride, is allowed to run by gravitation through the precipitating vessels, K, where the chloride is decomposed and the metallic gold deposited.

Care must, of course, be taken to thoroughly wash out the soluble gold contained in the chlorinator, after which it is inverted, the lid, L, opened, and the contents discharged into the truck, M, and removed to the waste heap. The process is thus rendered as automatic as possible, and with ordinary care the loss is reduced to a minimum.

Early in 1890, I had occasion to make a trial of this process upon a sample of refractory ore from Norway, with the following results, which will be found interesting:—The ore weighed 4 tons 10 cwt., and consisted of quartz containing calcite and iron pyrites, assaying before treatment 10 oz. 8 dwt. of gold per ton of 2240 lb., partly in a free state and partly associated with iron pyrites. The ore was crushed, roasted, and chlorinated on the Newbery-Vautin system, and the total gold obtained was 5 oz. 18 dwt., or equal to 1 oz. 6 dwt. per ton of ore.

THE CYANIDE PROCESS FOR REFRACTORY GOLD ORES.—The cyanide process differs from the chlorination in one very essential feature, and that is, that the auriferous ore does not require a preliminary roasting operation. The ore, whether as “tailings” or as pulp direct from the stamps, is conducted direct into large wooden vats, and is then treated with a weak solution of cyanide of potassium, which dissolves out the gold. This solution is then drawn off into a precipitating vat containing zinc turnings; the zinc is dissolved and the gold precipitated from the solution, to be collected and smelted into bullion.

Such is a brief outline of the process which has recently been brought into extensive and successful working, both in South Africa and America, for the recovery of gold from refractory ores. Properly speaking, no machinery is employed, unless the large wooden vats come under that head. But so much has of late been heard of it in connection with the Witevatersrandt Mines, that a notice of it will not be altogether out of place in continuation of what has already been written on the roasting and chlorination of refractory gold ores.

On its first introduction it was thought necessary to agitate the material under treatment with the cyanide solution, in order to facilitate the extraction of the gold; but this idea has now been abandoned in favour of allowing the solution to percolate through the ore or tailings, which are charged into wooden vats of a capacity of from 35 to 50 tons each.

These vats may be either round or square. Those in use at the Robinson Gold Mines, Johannesburg, are circular, and have a capacity of 75 tons; while at the Langlaate Mines there are tanks to a capacity of 400 tons.

The vats are filled to within a few inches of the top, and the surface of the ore levelled. A solution containing from .5 to .8 per cent. of cyanide is then introduced until the tank is filled, and is allowed to remain in contact with the ore for a period of about 12 hours.

The bottom of the vat is formed into a filter of coarse sand and pebbles, covered over with cocoa-nut matting, and is drained by means of an iron pipe leading to the precipitation vats. At the end of 12 hours a tap in this pipe is opened, and the solution is

drawn off, being replaced by a fresh quantity in order to ensure the whole of the gold being dissolved. This second solution is allowed to stand for a period of from 6 to 12 hours, and is then drained off to the precipitation vat; after which the ore in the leaching vat is first washed with a weaker solution containing from .2 to .4 per cent. of cyanide, and finally with water. The weak solution is not allowed to drain into the same precipitation vat as the two former, but is run into a separate tank called the weak zinc box.

The cyanide of potassium is supplied in cases holding from 190 lb. to 195 lb. in the form of white cakes, and from these a concentrated standard solution is made, from which the dilute liquor can readily be prepared.

The actual amount of cyanide used is about half a ton of the strong (.6 to .8 per cent.) solution, and half a ton of the weak (.2 to .4 per cent.) solution for every ton of ore treated.

As the amount of cyanide solution required to dissolve the gold is extremely small, it is the practice in some works to pump it back into the same tank for about 36 hours before running it into the precipitation vat. By this means the consumption of cyanide is greatly reduced, and a much smaller quantity of it exposed to the action of the zinc.

The cyanide solution containing the gold is led for precipitation through an iron pipe to the "zinc box." At the Calumet Gold Mines in the States this box is made of wood, and is about 14 ft. long, divided into fourteen compartments, each of which has a wire screen near the bottom upon which there is a 4-in. layer of zinc shavings. The boxes are so constructed that the solution is made to pass through the body of the shavings, which precipitates the gold and silver, if there is any, in the form of a blackish powder. A certain amount of zinc enters into solution to replace the gold; but this is not apparently deleterious to the process as the solution is pumped back after passing through the precipitation tanks for use again in the leaching vat, a certain amount of the standard cyanide solution being added in order to maintain its strength.

The precipitated gold is collected and smelted in the usual manner.

As to the cost of the process, in America it is said to vary between \$2 and \$5 per ton, but in South Africa it is stated that tailings containing 5 dwt. can be worked so as to give a profit, not only to the mine, but also to the African Gold Recovery Company, Ltd., who are the proprietors of the process.

At the present moment,* the New Primose Gold Mining Company, of Johannesburg, are erecting a cyanide works to treat 15,000 tons of tailings per month. There will be thirty filter vats, each 20 ft. diameter and 6 ft. 9 in. deep, constructed in three rows of ten each. The solution will be stored in six tanks of the same size as the filter tanks, but placed at a height of 16 ft. from the ground. There will also be six extracting or precipitation boxes. The vats will be filled with ore from an overhead tramway, and the discharge will be arranged for at the sides low down.

The building is 246 ft. long \times 80 ft. wide, and in addition to the tanks and vats will be provided with four Tangye pumps for circulating the solutions.

I am indebted for much of the above information to the *South African Mining Journal*, in the columns of which will be found much useful information on this subject.

* January, 1893.

CHAPTER XXV.

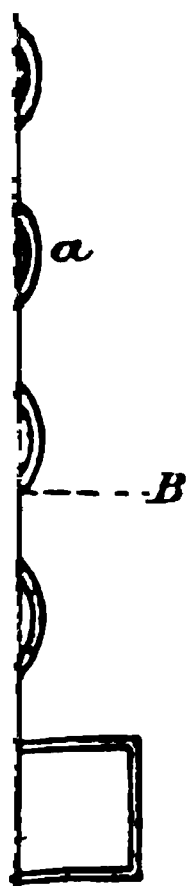
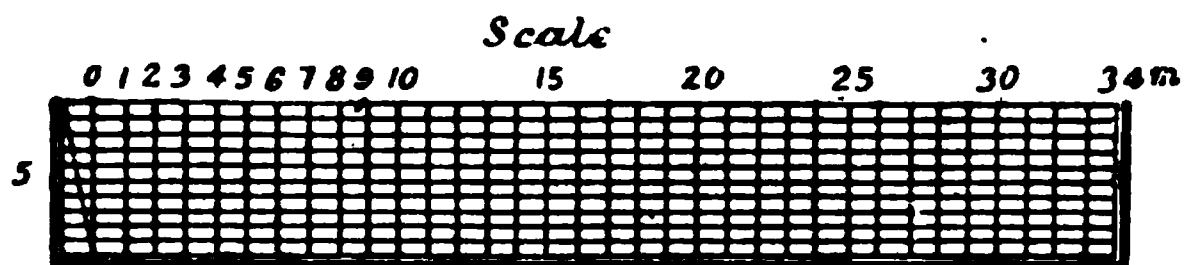
*CONCENTRATION MILLS OR DRESSING FLOORS FOR THE
ORES OF LEAD, ZINC, COPPER, ETC.*

Mill at Arrayanes, near Linares, Spain, for Argentiferous Lead—Mill at NeuhoF Mine, near Tarnowitz, Upper Silesia, for Lead and Calamine—Description of Mill and Results Obtained—Small Plant for Lead and Zinc Ores.

LEAD DRESSING OR CONCENTRATION MILL ON THE GERMAN MODEL. —The German manufacturers of concentrating machinery justly attach great importance to the classification of the mineral, and divide their trommel systems with such care that the grains as sent to the jiggers are as near as possible all of the same size for each machine. This method will be noticed in the following description of a mill erected by the Humboldt Company, of Kalk, near Cologne, for the Arrayanes Mine, at Linares, in Spain. The mill is a large one, designed to and capable of treating 500 tons of ore in 10 hours. It is built on the slope of a hill, so that the ore runs automatically through the machines, thus avoiding much expensive handling and the elevation of the mineral for re-treatment.

In the illustrations (Plates I. and II.), the lettering is identical. They consist of a plan of the whole mill (Plate I.), a longitudinal section (fig. 251, Plate II.) on the line, A B, of the plan, and various cross-sections (figs. 252—256) through each of the departments.

The mineral arrives from the mine at *a* in the plan (Plate I.) and section (fig. 251, Plate II.), and is tipped into the masonry kilns or bins, *b*, from whence it slides on to the fixed picking



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tables, *c*. These tables are covered with grates having holes 30 millimetres square, and here the first classification commences.

The rich mineral is hand-picked out and sent to magazine. The mixed ore is trammed to the elevator, *f*, and on to the stone breakers in department II.; while the ore which passes through the grates descends into department I., where it is classified in the two parallel sets of trommels, *d*. The holes in each of these sets in descending order are 22.6, 16, 8, 4 millimetres.

There are two jiggers to each trommel, making in all the sixteen, shown at *ee*.

The water used in the trommels and in the kilns is pumped back again by a centrifugal pump, *h*, in fig. 253, to the tank, *i*. This pump runs at 1500 revolutions per minute.

The water used in the jiggers of department I. is also pumped back by another centrifugal pump at *h*, and used over again. This second pump runs at 600 revolutions. Department I. is driven by a separate engine, *g*, with a cylinder 300 millimetres diameter \times 400 millimetres stroke, fitted with a separate condenser, and running at a speed of 105 per minute.

Passing on with the mixed ore—that is, the lumps of ore which require crushing in order to separate the rich from the sterile—we arrive at the two stone breakers, *jj*, of department II.

These breakers have a jaw opening of 400 \times 200 millimetres, and run at a speed of 200 revolutions. They are each followed by a double trommel, having holes of 16 and 18 millimetres, which take out the small stuff and send the coarse on to the revolving picking tables, *ll*, each of which is 3 metres diameter. A further separation of the rich from the poor by hand here takes place; the poor is swept off the tables, which are of the type shown in fig. 136, and passes direct into the roller crushers, *kk*, of which there are two pairs, one under each picking table.

The rolls have a diameter of 950 millimetres (say 38 in.), and a face of 300 millimetres (say 12 in.), revolving at a speed of 40 revolutions per minute. The crushed ore passes on to department III., where it is classified in two sets of four trommels, *oo*, shown in the plan (Plate I.), and in the sections (figs. 251 and 254).

These trommels have holes of 16, 8, 4, 2, 1 millimetres respectively in each set, and there are two jiggers for each trommel, making in all the sixteen shown at *pp*, in the plan and sections. The water is supplied by the California pump, *s*, and is pumped back to the tank, *t*, in fig. 251.

The departments II., III., and IV. are driven by a coupled condensing engine, *n*, on the plan, having cylinders each 350 millimetres diameter (14 in.) \times 700 millimetres (28 in.) stroke, running at a speed of 100 revolutions per minute; the steam being supplied by three double-flued boilers, 8 metres long, as shown on the plan.

The mixed products from the jiggers which require enriching pass on to the two pairs of fine roller crushers, *r r*, in the plan and longitudinal section. These rolls are 700 millimetres diameter \times 280 millimetres face (28 in. \times 11½ in.), running at 45 revolutions. They are each followed by a guarantee trommel, *z z*, which prevents any ore coarser than 1.7 millimetre from being carried on to the classifier, *u*. This classifier is one of the type described on page 277, fig. 172, with an ascensional current of water. It is 5½ metres long, and supplies the four slime jiggers, *w w*.

The fine slimes are carried over to the spitzkasten, *v* (described on page 279), where they settle and thicken. The waste water flows over into the tanks, *y*, and the slimes are distributed over the Linkenbach tables, *x' x'*, of 6 metres diameter, and *x x*, of 7 metres (see page 310, and figs. 198, 199).

The whole of the ore which arrived at the kilns has now been gradually classified and separated into marketable mineral and steriles, with as near an approach to an automatic action as is possible, and the results obtained were very satisfactory. The building is made of a framework of wrought-iron girders, covered with corrugated iron.

The German firm who supplied the machinery always insist upon making an experimental trial of a few tons of the ore at their own works before they will recommend or supply any type of machinery, and this is a matter in which the English firms would do well to imitate them.

MIXED ORE CONCENTRATION MILL. — The following is a

FIG. 234.—SECTION E F.



FIG. 235.—SECTION G H.



FIG. 236.—SECTION I J.



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description of a mill for the concentration of a mixed ore containing galena and calamine, built by the Humboldt Manufacturing Company of Kalk, near Cologne.

The mine NeuhoF, belonging to the "Hugo Graf Henckel von Donnersmarck" Company, at Carlshof, near Tarnowitz, in Upper Silesia, is situated at about two miles to the north of Beuthen, near the railway station of Scharley. At this mine some beds of galena, containing bunches of calamine in a dolomite gangue, are worked. The beds, which have a thickness of about 7 metres, are found at a depth of from 35 to 50 metres, and dip towards the south. At a greater depth of from 75 to 100 metres they lie upon layers of pyritiferous blende. The calamine and dolomite are often ferriferous. The galena is found in grains varying in size from 25 millimetres (1 in.) down to fine sands and slimes, and is rarely found combined with the gangue cerusite (carbonate of lead); also occurs in a finely divided state, or as an incrustation upon the grains of galena. The mineral is comparatively soft, and the separation of the calamine from the galena presents no difficulty, because of the great difference in their specific gravities; but, on the other hand, the dolomite and calamine cannot be completely separated, for these two are intimately mixed up together, and form intermediate products of all kinds. The cerusite is somewhat porous, and it is probable that the lighter particles are floated off on the water employed in dressing.

The galena contains a certain amount of silver, and in the new dressing mill the points to be attained were a minimum loss of galena and cerusite, and the prevention of the loss of the lighter particles of cerusite.

The dolomite and calamine are intimately mixed together, and the former always contains more or less of the latter. The pure lumps of calamine contain about 45 per cent. Zn, but ore containing over 8 per cent. Zn is mixed in the smelting furnaces with richer mineral. In the former dressing mills the large lumps of mixed mineral were broken either by hand or in a rock breaker, and afterwards separated by hand-picking, as when the minerals were intimately mixed their separation could not be effected at a profit.

The calamine formations in Upper Silesia are often very argil-

laceous, and in the mine under notice the clays were so tenacious that in the washing trommels they formed balls which contained precious mineral, and this could not be divided even when abundance of water was used. In designing the new dressing mills it was absolutely necessary to prevent the formation of these balls of clay, as they always contained the richest mineral, and after numerous experiments it was found that this could be attained by using the "Criekboom" trommels.

The preliminary trials made with a quantity of the mineral sent for experiment to the works of the Humboldt Company, at Kalk, near Cologne, gave the following results, which furnished the basis for the designing of the works afterwards erected.

After leaving the Criekboom trommel the slimes were passed on to a trommel having holes of 2 millimetres, and were then classified by means of a classifier, with an upward current of water and two spitzkasten.

The classified slimes were fed respectively into a 3-compartment jigger, a percussion or Rittinger table, and a rotating table of 4 metres diameter. The products were galena, calamine, and steriles.

The material larger than 2 millimetres was classified in trommels as follows:—2 to 2·8 millimetres, 2·8 to 4 millimetres, 4 to 5·6 millimetres, 5·6 to 8 millimetres, 8 to 11 millimetres, 11 to 16 millimetres, and 16 to 22 millimetres, each category being sent to a jigger, and the stuff larger than 22 millimetres being hand-picked.

The *quantitative results* of this trial were as follows, the total weight of ore treated being 8970 kilogrammes:—

<i>Galena</i> : Grains from 2 to 22 mm. . .	894 kg.	
„ less than 2 mm. . .	129 „	
Slimes from Rittinger . . .	12 „	
„ Rotating table . . .	5 „	
	<hr/>	
	1040 kg.	
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Weight production of Galena . . .	= 11·60 %.	
„ „ Calamine I. 3384 kg. . .	= 37·20 %.	
„ „ „ II. 1258 „ . .	= 14·00 %.	
„ mixed products . . .	38 „ = 0·42 %.	
„ sterile . . .	3290 „ = 36·78 %.	
	<hr/>	
	8970 kg. 100·00 %.	

The qualitative results by analysis were as follows:—

(a) GALENA.

	Grammes.
Hand-picked larger than 22 mm. }	82.41 % Pb with 14.74 Ag per 100 kilos.
Grains from 2 to 22 mm.	76 to 82.55 % Pb „ 25 to 101.52 „ „
„ less than 22 mm.	72.32 % Pb „ 81.2 „ „
Slimes from Rittinger and rotating tables }	62.58 to 70.13 Pb „ 24 to 50 „ „

The average assay of the crude ore was 7.75 per cent. Pb, 8.03 per cent. Zn, and 8 to 10 per cent. of iron, per ton of 1000 kilos.

(b) CALAMINE.

Hand-picked larger than 22 mm. gave	16 % Zn.
Grains from 2 to 22 mm. „	11.43 to 21.53 % Zn.
Sands under 2 mm. „	16.37 % Zn.
Slimes from the Rittinger table . . . „	14.37 % Zn.
„ „ Rotating table . . . „	8 % Zn.

The calamine No. II. was enriched up to 12.65 per cent. The steriles contained an average of 5.40 per cent. Zn. The calamine was of an average percentage of 14.76.

The calamine in large pieces, which was not subject to this experiment, contained an average of 17 to 18 per cent. Zn, while the sterile slimes from the trial held 1 per cent. Pb, and the mixed products 25 to 47 per cent. Pb, with 18 grms. Ag per 100 kilogrammes of mineral.

The result of the trial was to prove the efficacy of the Criekboom trommel, and the utility of the tables in saving the silver, which would otherwise have been lost in the slimes. In order, however, to ease the work of the tables, it was proposed to employ the Bilharz circular jiggers and the fixed Linkenbach table, whose diameter could be as large as 10 metres, and which would thus give the slimes a longer interval of time in which to classify themselves before leaving the table.

The results of the experiment being thus favourable, it was decided to erect a new concentration or dressing plant, capable of treating 250 tons per 20 hours; in actual practice, however, the plant was found able to dress 300 tons in the same time.

The Humboldt Company was entrusted with the manufacture

and erection of the dressing machinery, and the boilers used were of the well-known "Root" system. The erection of the buildings was commenced in August 1884, and the first trial run was made on May 2nd, 1885; the mill was in full working order by the second half of the same month.

The cost of the complete installation, including the piping, but excluding the belting, was £5500, and the two boilers, each with a heating surface of 128 square metres, cost £500 apiece. The following is a description of the works which were designed for the enriching of a mineral containing argentiferous galena, cerusite, and calamine, with a gangue of dolomite. The mineral arrives in trucks, and passing through the doors, A A, of fig. 257, Plate III., is run into a cage, and raised to the upper floor of the works at a height of 11 metres above the ground by means of a small winding engine.

The waggons hold 450 to 500 kilos. (say half a ton) of ore, and are side tipping.

On the top floor there are two gratings, C C, of an area of 1 metre \times 1.40 metre, the bars being 70 millimetres apart. The waggons are tipped on to these, and the mineral is helped to pass through by means of a supply of water. The lumps which are too big are put on one side, and as their proportion is very small they are separated by hand. (The mineral is subject to a preliminary sorting in the mine, so that all mineral ready for hand-picking can go direct to that department.

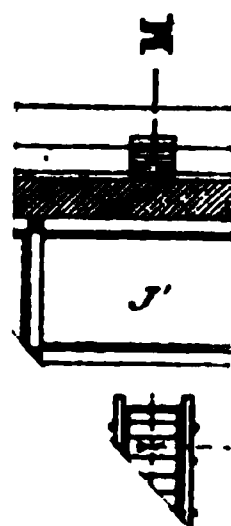
The mineral which passes through the gratings, C C, passes on to the two trommels, F F, in which a current of water forms with the ore a liquid mud, which is constantly stirred up in the trommel. The covering of the trommel is in sheet steel, and in the inside some steel blades are fixed in such a manner as to force the mineral forward, while at the same time a series of iron knives, revolving in the interior of the trommel at a speed of from 200 to 300 revolutions per minute, break up the balls of clay, and thoroughly mix up the mass.

Each of the trommels, F F, has a diameter of 1600 millimetres and a length of 2.500 metres, and runs upon friction wheels.

At the mouth of the trommel there is a sieve with longitudinal slots of 4 millimetres, so that the clayey mixture and all the grains

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less than 4 millimetres pass through this sieve into the general sluice, G, which leads them to a classifier, with upward current of water, H, in which they are separated into two categories.

1st. The large grains which have traversed the upward current of water, and are directed with a part of the water to the trommel No. 2.

2nd. The fine sands and slimes which are thrown over by the water, and which are led direct to the slime department.

The mineral matter coming from the washing trommel, F, which is over 4 millimetres in size, passes on to the large trommel No. 1, where a preparatory classification is effected. This trommel is 4.50 metres long, with an average diameter of 1.65 metre. It has two coverings; the exterior has holes of 2.5, 13, and 17 millimetres, the interior has holes of 10 and 22 millimetres.

The products from this trommel are divided as follows:—17 to 22 millimetres to the jigger No. I.; 13 to 17 millimetres to No. II.; 10 to 13 millimetres to the jigger No. III.

The two finer sizes each pass on to the two series of trommels placed underneath Nos. 3 and 6.

The lumps larger than 22 millimetres are swept by a current of clean water on to an endless belt, H' (figs. 257, 258, and 259), where they are hand-picked by a number of women.

The picked lumps are thrown into openings on each side of the belt, and through them into the magazine, J'. The steriles fall off the end of the belt into the magazine, J'. The mineral is fed automatically from the magazines into waggon as and when required.

The trommel No. 2, referred to above, is under the large trommel No. 1. It receives the mineral which has passed through the upward current of water in the damper, H, and divides it amongst the trommels No. 3 to No. 8. All these trommels are conical, 1.650 metre long \times 900 millimetres average diameter. The trommel No. 2 is double; the interior covering is perforated with holes 1.9, and 2.5 millimetres diameter, the exterior with hole of 1.3 millimetre. The six other trommels are simple, with holes respectively of 8—5, 4—4, 1.9, 1.3, and 1 millimetres diameter.

The trommel No. 2 gives a product 1.3 to 2 millimetres, which

is sent to the jigger No. IX. The product 1·9 to 2·5 millimetres goes to the jigger No. VIII. The mineral under 1·3 millimetre goes to the trommel No. 8, and that larger than 2·5 millimetres to the trommel No. 5.

The mineral rejected from trommel No. 3 goes to the jigger No. IV.

"	"	"	"	"	4	"	"	"	V.
"	"	"	"	"	5	respectively	to	Nos.	VI. and VII.
"	"	"	"	"	6	"	"	"	VIII.
"	"	"	"	"	7	"	"	"	IX.
"	"	"	"	"	8	"	"	"	XI.

And, lastly, the mineral passing through the holes of the trommel No. 8 is treated in the jiggers XII. *a* and *b*.

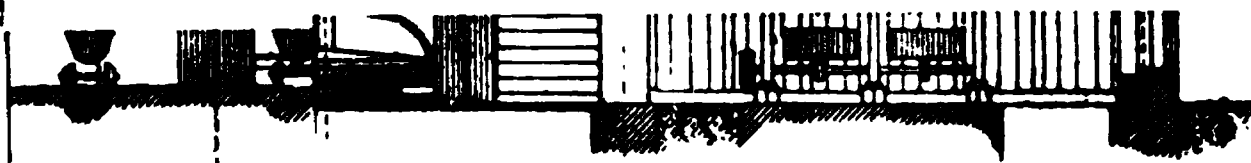
The channels are all of such a slope as to admit of the mineral passing automatically from one machine to another. The trommels are all kept clear by means of water-sprays, and the perforated sheetings are fixed by means of bolts and angle iron, so that they may be readily repaired.

The preparatory trommel No. 1 is driven from the main shafting, but by means of intermediate gearing, so as to reduce the speed. The following seven trommels are driven by one belt only, which, starting from the axle of No. 1, winds over and under all the pulleys or the trommels 2 to 8.

The jiggers I, II., III., and IV. are of three compartments, with side delivery, and throw off the finished products through regulating sluices.

The other jiggers are of four compartments, with sieves 450 millimetres broad \times 750 millimetres long. The body of the jiggers is made of pitch-pine planks 60 millimetres thick, grooved and tongued. The sieves have square holes, and are fixed in their places by means of copper wire upon a grating with fine bars. The water and mineral can flow out from the bottom by means of a valve, closed and opened by means of a lever.

The jiggers are all upon the differential lever-stroke principle shown in fig. 183, page 290; the descent of the piston is rapid and its ascent slow, and thus effects a better classification than the usual eccentrics, for in the former case there is not the suction which is always present in the latter; and, lastly, the



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LINE G H.



MILL FOR LEAD

friction and wear and tear are less. The levers are so arranged that whilst one half of the pistons is descending the other half is rising, and this disposition, in conjunction with the circular masses forming flywheels, permits of a much more even running of the jigger and less strain on the belt.

The product of the jigger is—upon the first sieve, pure galena ; from the second a mixed product, dolomite or calamine mixed with galena ; on the third a rich calamine, No. 1 ; on the fourth, a poor calamine, No. 2, and the steriles which pass through the adjustable opening leading from the fourth compartment. The mineral matters thus separated are automatically transported to the magazines, the bottoms of which are made of perforated sheeting so as to allow of drainage ; and this sheeting is removable, and permits the mineral to fall automatically into the trucks.

The steriles are thrown away ; the mixed products are relifted to the upper story, and ground in the rollers, K K, from which they pass to their respective trommels.

Such is the arrangement for washing, hand-picking, classifying, and jiggering the coarser grains ; and we now pass on to the *slime* department, which is situated to the west of the other buildings, and is fed by—

1. The overflow of the classifier with upward current, H.
2. „ „ „ „ placed in front of the jiggers XII. and XII. a.
3. The slimes which are deposited in the coarse jiggers.
4. The mud deposited in the settling tanks of the mill.

The slimes from the jiggers run into a tank, M, from which they are lifted by means of an elevating wheel, N, of fig. 257, Plate III., and fig. 263, of Plate IV. This wheel has a diameter of 6.50 metres, and empties the slime water into the trough, O, into which the overflow of the classifier, H, is also emptied.

The overflow from the apparatus, H', is emptied direct into the classifier, L (figs. 261, 262, and 264). The mud coming from the slime pits is deposited in the basin, M, to be elevated by the wheel, N. In order that any coarse grains may not find their way into the classifier, L, the slime waters are first of all made to pass through a guarantee trommel having holes of $1\frac{3}{4}$ millimetre. The

grains rejected by this trommel return to the jiggers, but the slime waters which pass through it are led to the classifier, L.

If all the water raised by the elevating wheel were allowed to flow through the guarantee trommel, the strong current of water would certainly carry grains of sand, and fine sieving would be impossible. In order to avoid this inconvenience a concentration apparatus, P, is fixed near the entry to the trommel. Here the waters from the elevating wheel are divided into two parts—1st, the coarse sands which go on to the guarantee trommel; 2nd, the overflow which passes direct to the classifier, L.

This piece of apparatus is made of wood of a length of 10.50 metres, of which a description will be found on page 277, and in figs. 172 to 175. Throughout its length there is an inner lining converging to a point at the bottom—shown in section at L, fig. 261—but leaving a longitudinal slit at the bottom, through which a constant upward current of water ascends; and this, in conjunction with the stream of slimes, whose speed is greater at the entry to than at the exit from the classifier, acting upon the tendency of the mineral matter to fall according to its gravity and size, classifies the grains which pass on to the slime jiggers through syphon tubes, as follows:—

1st. To the three jiggers R' R'' R''' each of four compartments similar in all respects to those before mentioned. Here the products obtained are galena, a mixed product, calamine No. 1, calamine No. 2, and steriles.

2nd. To the first circular or Bilharz jigger, s', which yields a product containing 25 to 30 per cent. Pb, and throws off the rest to a second jigger, s'', placed on a lower level. This jigger produces a rich calamine, and discharges into the main waste water channel. It is described fully on page 291.

The overflow of the classifier, L, is divided between the three spitzkasten, v' v'' v''', in which the fine slimes are concentrated. These latter are conducted by means of a syphon tube passing under the floor to the centre of the Linkenbach table, V., for a full description of the action of which see page 311, and figs. 198 to 200.

The products of the table are accumulated in four cases, of which one is under the spitzkasten, v', and the three others are outside the building.

The waste waters from the spitzkasten and the cases of the table pass first of all into four preparatory basins, and then into the main slime pits, where they are clarified by settling. Of these there are four, each of an area of 40 metres and a depth of 4 metres. A single basin is sufficient for the accumulation of slimes during two-and-a-half to three months. They are constructed in masonry, and in the centre of the four walls is a circular pit, at the bottom of which are the mouths of four galleries, each of which ends at the lowest point of each of the basins, which is closed with planks.

When it is desired to empty a basin the planks are removed, the slime loaded into trucks, which are run to the pit and raised by a winch.

The clarified waters are led back to the centrifugal pump, *p*, by means of which they are lifted to a reservoir 9 metres higher, from which point again a part of the water is raised another 9 metres by means of the centrifugal pump, *p'*. (See figs. 259 and 260, Plate III.)

The classifying trommels, the classifiers, picking table, and Linkenbach table are supplied with fresh, clean water, which is supplied from a reservoir at some distance from the mill. All the other machines receive the clarified water from the settling pits.

In the driving gear the use of toothed gearing has been minimised, and in no case are cone wheels used. There are four main lines of shafting, of which the principal is driven by means of cables from the steam-engine. To these the machines are connected by means of indiarubber belting. All the shafts are turned for their full lengths, and the pulleys are all made in halves—split pulleys.

The engine has a cylinder 620 millimetres diameter stroke, 1250 metres steam-jacketed fitted with Zimmerman valves, and running at a speed of 54 per minute. The speed of each separate apparatus is marked on the plans thus:—*n* 120, *n* 150, and so on. The condensed water from the engine is turned into the settling pits, and so to the centrifugal pump. It is hoped that this will prevent the mill from being frozen up in the winter.

The galena and calamine are trammed to the smelting furnaces for lead and zinc respectively.

454 CONCENTRATION MILLS OR DRESSING FLOORS.

In the month of August 1885, the total amount treated in the mill was 6750 tons, of which 5160 came from old waste heaps, and 1640 from the mine direct.

The results of the milling of this amount were :—

Galena	15	tons	hand-picked.
„	76·65	„	coarse jigs.
„	88·8	„	fine jigs.
„	34·5	„	coarse slimes.
„	5·05	„	fine from tables.

Total 220 tons = 3·26 % of the crude ore.

Calamine	196	tons	hand-picked ore.
„	228	„	coarse jiggers.
„	177·5	„	fine „
„	80·0	„	slimes from tables.

Total 681·0 tons = 10·10 % of crude ore.

In September 5561 tons of crude ore gave

Galena	.	.	.	230 tons = 4·14 %.
Calamine	.	.	.	600 „ = 10·7 %.

The galena from the jiggers, I. to VIII., assayed :
78 to 84 per cent. Pb. The Calamine I., from 15 to 34 per cent. Zn, and the Calamine II., from 10 to 20 per cent. Zn.

The steriles assayed on an average 0·3 per cent. to 0·5 per cent. Pb, and from 4 to 5 per cent. Zn.

The jiggers, IX. to XII., gave :

Galena	.	.	.	from 60 to 75 % Pb.
Calamine I.	.	.	.	„ 18 „ 30 % Zn.
„ II.	.	.	.	„ 10 „ 15 % Zn.

The steriles as above.

The fine slime jiggers gave :

Galena.	.	.	.	70 to 76 % Pb.
Calamine I.	.	.	.	15 „ 23 % Zn.
„ II.	.	.	.	9 „ 13 % Zn.

Steriles with 0·5 per cent. Pb and 5 to 6 per cent. Zn.

The circular jiggers, Bilharz, enriched the slimes on the first sieve to 20 to 26 per cent. Pb, and the second sieve gave a product containing 10 to 12 per cent. Zn, with 2 to 3·5 per cent. Pb.

The steriles gave 0·75 per cent. Pb and 6 to 8 per cent. Zn. The calaminiferous slimes were enriched on the Rittinger tables (percussion) W and W" (fig. 257, Plate III., and fig. 264, Plate IV.).

The products from the Linkenbach table were lead slimes with from 50 to 60 per cent. Pb, and calamine slimes with 8 to 10 per cent. Zn, and 1½ to 2 per cent. Pb.

The slimes from the Linkenbach tables contained ½ to 1 per cent. Pb, and 6 to 9 per cent. Zn.

The slimes enriched on the percussion tables yielded from 40 to 46 per cent. Pb.

The quantity of silver contained in the dressed products was as follows :—

Jiggers I. to III.	.	42 to 62	grammes of Ag per 100 kilos. of mineral.
„ IV. „ X.	.	60 „ 120	„ „ „ „ „
„ XI. „ XII.	.	80 „ 110	„ „ „ „ „
The three fine jigs	.	80 „ 110	„ „ „ „ „

The concentrated slimes from the Bilharz jiggers, the Linkenbach table, and the percussion tables gave 50 to 60 grammes of silver per 100 kilos. of mineral.

The hand-picked mineral contained 24 grammes Ag.

The *cost* of the whole milling operations amounted to 0·125 francs per 100 kilos. of mineral, which is equal to about 1s. per ton of crude ore, a price which will compare very favourably with that of any other system of dressing, while the results obtained were very good, considering the complicated nature of the ore which was under treatment.

The plans of the mill will well repay a careful study, and it will be noticed that the whole operation is automatic.

The mineral is not touched by hand until it is finished with, while the products fall direct from the jiggers into the tram-waggons placed below.

SMALL CRUSHING AND CONCENTRATION PLANT.—There are

many mines which, from the nature of their lodes, situation, and for financial reasons, cannot ever develop into large undertakings, and where, consequently, it would not be wise to put up the most perfect but somewhat expensive plants just described.

For these small mines, especially where there is an abundance of water supply, a plant such as that illustrated in fig. 265, is perhaps the most suitable, although high-grade concentration must not be expected from it. This style of mill is in use in Wales, though unfortunately, owing to the fall in the value of lead, many of the mines at which these mills were erected are now lying idle. The ore as it comes from the mine is tipped over a kiln or bin, from which it is raked out at the lower end on to grates, where it is hand-picked over by women who take out the rich ore. The remainder is then spalled or broken up by hand, though now stone breakers are sometimes used for this purpose, and then wheeled into the crusher-house on the left of the section, fig. 265. Here it passes through rollers 26 in. diameter, A A, in the section, and shown provided with the old-fashioned lever arrangement for closing them up instead of the indiarubber buffers now in general use. Underneath the rollers is the sorting trommel, B, which separates the insufficiently-crushed mineral and sends it back to the rollers by means of the elevator, *b*. The other mineral passes through a slime cone, which drives off the fine slimes, and then through the series of trommels, *c*, *d*, *e*, which classify it into sizes varying with the kind of ore, and distribute it to the jiggers, C, D, E, by means of the chutes, *c*, *d*, *e*. The slime waters containing the fine grained mineral, pass over wooden, inverted cones, *f*, *g*, *h*, each having an upward current of water, and, after being thus classified, are treated in the jiggers, F, G, H. The fine slimes are enriched on the circular buddle, I, after a part of their excess of water has been got rid of in the settling tank or spitzkasten, K.

The jiggers are of three compartments, with the ordinary eccentric motion as described on page 283, and the details of a buddle are shown in fig. 188.

The whole mill is driven by a waterwheel, but there is no provision for recrushing the mixed ores, and the arrangement for treating the slimes is somewhat wasteful.

For small undertakings however the arrangement is not unsuitable, because simple and inexpensive and if a stone break table and fine crushing added, it would be economical, and recover percentage of lead.

The slime waters, after wooden settling tank, are in a series of slime pits, where matter is deposited, which is afterwards dug out, and, if required, put through the buddles and a first well mixed up with stirring machine called *stirrer*, such as that illustrated in fig. 177.

Before the introduction of perfect machines of the present type the dressing of lead ore was conducted largely by hand made machines, such as the *jigger* shown in fig. 177, which superseded the use of sieves for jigging, the use of which is illustrated in fig. 176. The crushed ore was roughly or not at all classified into sizes before being thrown into the sieve of the jigger, which is suspended by the iron rods, *a a*. The woman then works the lever, *b*, up and down, and this rocks the lever, *c*, from which the sieve is hung, but owing to the play allowed at the joint, *e*, a blow is

FIG. 175.—SECTION OF SMALL LEAD CONCENTRATION MILL.

struck at each stroke of the jigger, which assists the separation of the rich from the poor ore. The rich ore forms itself in a layer at the bottom of the sieve, covered with a layer of mixed ore and steriles. The slime waters run across settling tanks, from which the slimes are dug up and treated on a flat or a round buddle.

The history of the development of the present machinery from the crude appliances of the past would be of great interest, but in this work, which is devoted to the modern appliances of mining, I can make but the short reference to them which I have just given. I may, perhaps, at this point, utter a word of warning against the unreasoning and hasty adoption of a process because it happens to be new. It is useless hiding the fact that many mining companies have been ruined, without any reference to their mines, through men deciding on the reasonableness of new process and machinery who have no knowledge of the business in hand. It is assumed often, that if an inventor or manufacturer of new machinery will agree to guarantee success, or take no pay if not successful, the company takes no risk. In actual fact a whole year is wasted in most cases, failure spoils the reputation of a company, running expenses have continued, and further working capital cannot be raised, because all concerned have lost confidence by the failure to obtain the returns promised. All this in addition to the regular, unavoidable risks of mining itself, which may, at any moment during the year lost, call for increased expenses and increased faith in ultimate success. To the mining man who makes money by the business, the natural risks of mining is all he will take : it is sufficient ; and when he invests more money in machinery he takes good care that he takes no chances of either failure or delay.

After the mine has become a dividend-paying property, then a few experiments can be indulged in without materially affecting the shareholders' pocket, but until then both the manager and directors alike should be prohibited from wasting the shareholders' money, and courting disaster by running after new and untried methods of crushing, concentration or amalgamation. A thoroughly experienced manager will not need to be reminded of this, nor will he risk his reputation by speculating in improvements which may probably jeopardise the success of the undertaking.

CHAPTER XXVI.

OTHER METHODS OF CONCENTRATION, ETC.

Dry Concentration Processes—Failures—The Clarkson-Stansfield Dry Concentrator—Dry Classifier—Results—Magnetic Ore Separation—The Monarch Magnetic Ore Separator—The St. Lawrence Iron Sands—Results of Magnetic Ore Separation—Power and Water required for various Mills—Belting.

DRY CONCENTRATION.—In many parts of the world the scarcity of water or the cost of obtaining it forms a serious drawback to the use of the usual wet concentration processes, and accordingly many attempts—mostly unsuccessful—have been made to substitute air for water and so concentrate by a dry process.

One by one these processes have been brought before the public, and after attracting some attention for a time, have gradually ceased to be heard of, and have not come into practical use, although in the hands of their inventors, and on a small scale, some of them have been quite successful in effecting a concentration, as I myself have witnessed.

The principle which has hitherto been experimented upon is roughly that of winnowing as applied to driving chaff from wheat in the well-known agricultural threshing machines, though in a few cases actual jigging with pulsations of air instead of water has been tried. A jigger of this type using compressed air, and known as Krom's Pneumatic Jig, is now attracting some attention in America.

On this side of the Channel an entirely new departure in dry concentration has been made, known as the Clarkson-Stansfield system. In its simplest form the machine consists of a rotating distributor and a fixed receiver. The ore, which must be absolutely

dry and perfectly classified, although in the shape of fine sand, is fed into the distributor, which is so arranged that the particles of ore are projected from it with a uniform angular velocity; the particles being of approximately the same size, those of lower specific gravity are sooner overcome by atmospheric resistance, and fall short, and are collected in one compartment of the receiver, while those of higher specific gravity are thrown further, and fall into a separate compartment. If, in the above description, we substitute quartz for the particles of lower specific gravity and galena for those of higher specific gravity it will be seen that the galena will be separated from the gangue of quartz. The principle

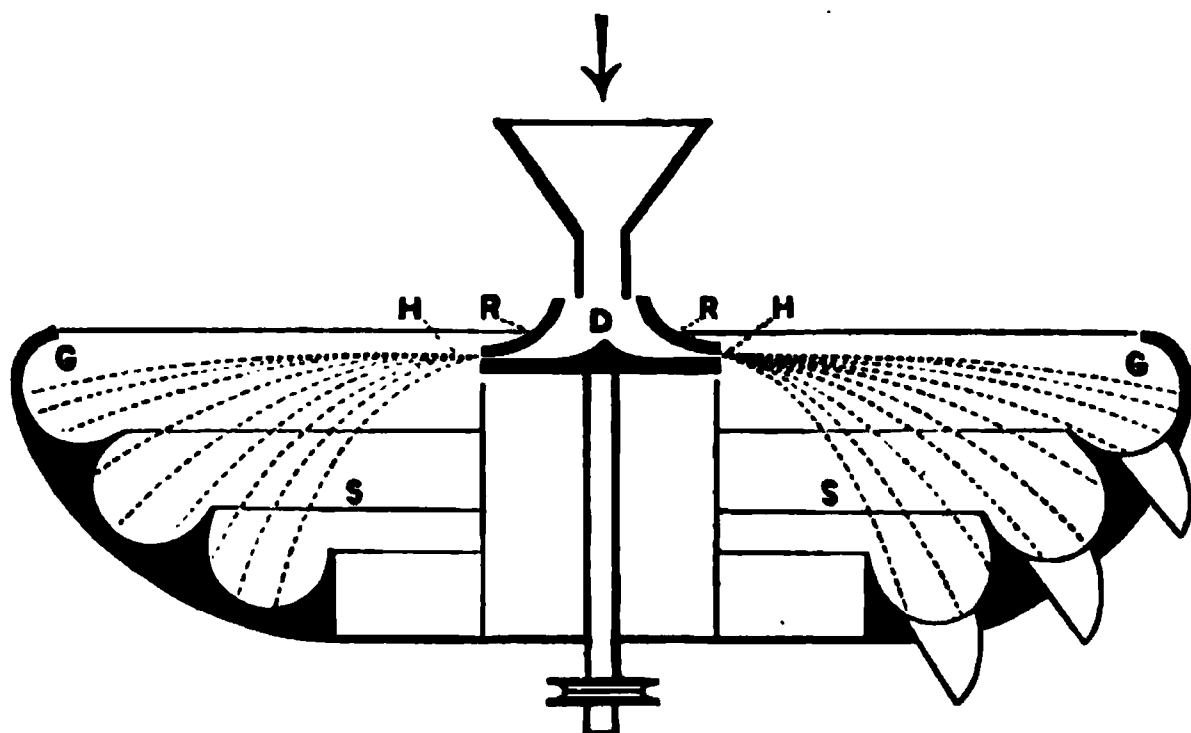


FIG. 266.—DIAGRAM SECTION OF THE CLARKSON-STANSFIELD DRY CONCENTRATOR.

of the machine can be tested by a very simple experiment, for if two objects of different weights but of the same size, say a marble and a bullet, are both thrown away together at an angle of about 45° , it will be found that the marble will fall at a shorter distance than the bullet.

The sketch given in fig. 266 will explain the action of the machine. The finely pulverised and classified dry ore is fed into the hopper from which it falls into a circular distributor revolving at a high rate of speed. The radial openings of the distributor discharge the ore in a constant umbrella-shaped stream as shown by the dotted lines. The rich, heavy particles of ore are projected into the outer concentric rings of the receiver, and the lighter

particles into the inner ones according to their relative specific gravities, while the sterile dust falls close to the distributor, and is indeed drawn downwards by a current of air produced by the motion of a fan placed below.

Provided that the ore has been previously classified with precision and absolutely dried, a perfect concentration is produced, and in order to obtain these two desiderata the inventors have perfected and patented two machines, a classifier and a dryer.

The classifier may be described in general terms as consisting of a number of screens superimposed and mounted in a simple but peculiar manner within a main frame.

The arrangement is such that the screens are always horizontal, and the operator can regulate with great accuracy the length of time during which the ore is permitted to remain on each screen. Revolving brushes sweep the under parts of the screens and prevent them clogging, and also propel the material passing through one screen on to the screen next below it. A powerful draught considerably increases the output of the machine, which is calculated to classify 40 to 50 tons per 24 hours. The screens range from 40- to 120-mesh, according to the nature of the ore.

Fig. 267 will give a good idea of the classifier, in which A is the hopper, B the screens, and C the chutes for the classified ore.

The process is worked on the following lines :—

The first operation is to put it through a rock breaker ; and, inasmuch as a considerable proportion of it comes from the rock breaker fine enough to pass a 40-mesh, that part is led directly to the classifier, and the remainder goes on to the crusher. The improved Krom rolls are superior to stamps for dry crushing, as they produce a minimum amount of slimes. At any rate, crushing the ore to pass a 120-mesh when a 40-mesh will do is to be avoided. The crushed ore should be as granular as possible.

From the crusher the ore goes on to the classifier, and is there graded into six different sizes, ranging from 40 to 120.

From the classifier the ore passes to the concentrator, of which fig. 268 gives a good view of the machine as constructed. The hopper of the concentrator is divided into six compartments, according to the different grades of ore, and as each one fills a valve at the bottom is opened, and the ore passes into the

distributor, and is thrown thence into the receiver, from which, as concentrates and tailings, it is swept by revolving brushes into chutes leading to wherever may be convenient. A slight alteration of the speed of the concentrator is required for the different grades, and the speed regulator enables this to be effected without stopping the machine. But a small portion of concentrates is on the machine at a time, and if there is any fear of peculation the chutes may lead direct into locked chambers.

The concentrates remain to be treated by smelting, chlorination, cyanide, or any suitable process.

FIG. 268.—THE CLARKSON-STANSFIELD DRY CONCENTRATOR.

As before stated, the ore must be perfectly dry, and should screen readily through a hand sieve of the required fineness before being put into the concentrator. Neither in crushing or in concentrating is there any middle course between the wet and the dry processes.

With skilled supervision and unskilled labour at the rate of 1s. per hour, it is estimated that these machines will concentrate for 1s. 4d. per ton. One skilled man can supervise, at least five machines concentrating altogether, say, 60 tons in eight hours, and should more than repay his cost by the saving in gold which ought to result from his supervision.

The total weight of a classifier and concentrator capable of treating 40 tons per 24 hours is under $5\frac{1}{2}$ tons.

The following are some of the results which have been attained in experimental work with full-sized Clarkson-Stansfield machines :—

A sample of Australian tailings assaying 7 to 8 dwt. gold yielded at one operation first-class concentrates assaying 7 oz. 16 dwt. 9 grs., and second-class concentrates assaying 2 oz. 12 dwt. 6 grs. The resulting tailings assayed 1 dwt. 7 grs. per ton. A Mexican ore, containing silver sulphides, the concentration of which is admittedly difficult, yielded at one operation first and second-class concentrates assaying 5 oz. 4 dwt. gold and 60 oz. silver per ton; the original ore assayed 4 dwt. gold and 9 oz. 5 dwt. silver per ton. As regards the separation of blende and galena the concentrates of an American ore from one compartment of the concentrator assayed 73·78 per cent. lead and 2·81 per cent. zinc, and from another 2·05 per cent. lead and 27·30 per cent. zinc.

The following is a description of a Clarkson-Stansfield dry concentrator, recently erected at a gold mine in Wales :—

The ore after being crushed is classified by sieves into 6 grades, V 12, 40, 50, 60, 70, 85, 100-mesh (sometimes more grades are necessary).

Each of the grades is delivered into a compartment of the bin, *f*, placed over the concentrator, and is there stored until sufficient of a grade has accumulated to run on to the concentrator, fig. 269.

It will be noted that at the base of each compartment is a valve connected by a pipe to the feed hopper, *c*, of concentrator. The valves are of the type illustrated, and they are opened and closed quite independently of one another by the hand levers shown, numbered and arranged, across the front of machine 1, 2, 3, 4, 5, 6.

The method of working the concentrator is as follows :—

Suppose that No. 2 compartment contains most ore. Before opening the valve and allowing the stuff to shoot down, the speed of the machine is adjusted for this grade, by giving the handle, *D*, a few turns until the speed is indicated on the dial, *E*, then

FIG. 269.—THE CLARKSON-STANSFIELD CONCENTRATOR AS ERECTED IN NORTH WALES.

the lever regulating the draft is set to No. 2. The driving belt is shown at *g*, and the revolving distributor at *a*.

The valve is then opened, and the ore rushes on to the machine. When the level of the ore in the hopper is up to the end of the delivery pipe from valve, it seals the opening, and stuff ceases to rush; consequently, although the valve is fully open, the amount of ore supplied from bin to hopper is exactly equal to the quantity delivered by hopper to concentrator. This may be regulated by an adjustable conical feed valve at base of hopper.

The concentrates are swept out of the receiver by the revolving arm *b*, into bags placed below, while the tailings from the inner part of the receiver fall into the pipe connected to the exhaust fan of machine, and are blown through a pipe laid underground, and delivering on the dump.

When No. 2 grade is worked off, its valve is shut, and the speed and draught of machine are then set for the next grade which is then fed on.

In this manner one concentrator may deal efficiently with several different sizes of ore, the adjustments for giving the same richness of concentrates from each having been determined by experiment at the first run.

In cases where the quantity of material to be dealt with is very great, it is better to devote a concentrator to every grade, so as to secure continuous running and a reduction in supervision.

The diagonal stays to bin, shown in photo. have been omitted, with other insignificant details in sketch, for sake of clearness.

MAGNETIC ORE SEPARATION.—Magnetic concentration has lately become an important industry in the United States.

Although the application of magnetism in the treatment of magnetic ores is not novel, it has not till within the last two or three years been looked upon as capable of successful demonstration on a commercial scale. The universal scepticism which prevailed regarding the practicability of this method arose from a variety of causes.

Through the kindness of Mr. A. T. Porter, I am enabled to give a description of the "Monarch" Magnetic Ore Separator. Before going into details, however, I shall give a few facts which may be of general interest regarding the earlier efforts, difficulties, and progress of this industry.

More than fifty years ago machines were constructed and patented for the purpose of concentrating the magnetic-iron sands of the St. Lawrence and other places, but further than that the patents set forth this fact, little is known how far they were successful. However, that they were not commercially successful, their non-existence at present would indicate ; nor is this result to be wondered at when we consider that the successful treatment of this material is the most difficult problem in magnetic concentration.

The St. Lawrence iron sands vary from 10 to 50 per cent. of magnetite, and from 5 to 15 per cent. of titanium, a large proportion of this latter being also magnetic, and as the presence of over $2\frac{1}{2}$ per cent. of titanium in the concentrate depreciates to a great extent the value of the ore, not only has the magnetic to be removed from the non-magnetic, but the two magnetic substances have to be separated. How difficult this latter is, especially on a large scale, can be readily appreciated when we consider the extreme fineness of the material, and that it is impossible to distinguish any difference between the titaniferous and non-titaniferous particles, even with the aid of a powerful glass, and as both readily respond to magnetic influence, it is only by the combined use of a hand-magnet and glass that a slight variation in their magnetic susceptibility can be discovered.

The "Monarch" machine is capable of such fine adjustment that it will take advantage of this slight difference, and so effect the separation of the titaniferous from the non-titaniferous particles on a successful commercial scale, as will be seen from the analytical table on page 471, drawn up from assays made by Mr. Riley. The small amount of middlings made and the large percentage of titanium it contains shows clearly the efficiency of the separator.

It is at present thought that the titanium remaining in the concentrate is evenly distributed through the whole mass. Should this, however, prove not to be the case, we may look for a yet further reduction of titanium in the concentrate. It is reported that English capital is now being subscribed with a view to erecting a large plant on north side of St. Lawrence, capable of treating 10,000 tons of sand daily.

The success of this process is doubly important, for not only are there large deposits of these iron sands in different parts of

the world, but there is also a large opening for such a machine for the treatment of auriferous iron sands, as well as the zinc ores containing magnetic iron.

The concentration of rock ore has also occupied the attention of inventors and investors for a great number of years, and it is no exaggeration to say that for this purpose hundreds of patents have been obtained in various countries.

At first the object sought was to increase the percentage of iron in the ore. Such was the case in a Swedish mine where the leaner portions of the ore were piled on waste dump, until the rich veins had in a measure become exhausted, when women and children with hammers were employed to detach and pick out the richer portions of these waste piles. What is known as a direct contact machine (in which the ore comes in direct contact with the magnets), was invented and substituted for this naturally slow and uncertain method, and with comparatively favourable results; but although this machine has been used for several years for "cobbing" purposes, there seems to have been no effort made to improve it, so as to meet the more critical requirements of ore concentration. Several attempts were made, and a large amount of money expended to utilise the vast deposits of titaniferous rock ore in the northern part of New York State, all of which resulted in failure, owing, it has been stated, to the titanium being too closely associated, and evenly distributed through the entire mass of the ore. How far the inefficiency of the separators used contributed to the failure of the enterprises is a question which can only be determined by an application to these ores of the latest improved methods.

To the development and extended use of the Bessemer process may be attributed much of the wonderful progress recently made in magnetic concentration, creating as it does a demand for ores low in phosphorus and sulphur, although the brisk competition in the iron business also created a demand for the higher grade of ores.

The illustration (fig. 270) represents a longitudinal section of the Monarch Magnetic Ore Separator, the joint invention of Mr. Sheldon Norton, of Hokendangua, Pa., and Messrs. C. M. Ball and A. T. Porter, of Troy, N.Y., U.S.A.

The apparatus consists of a partially-closed chest, having an opening at *f* from the feed-hopper, *h*, through which the ore is

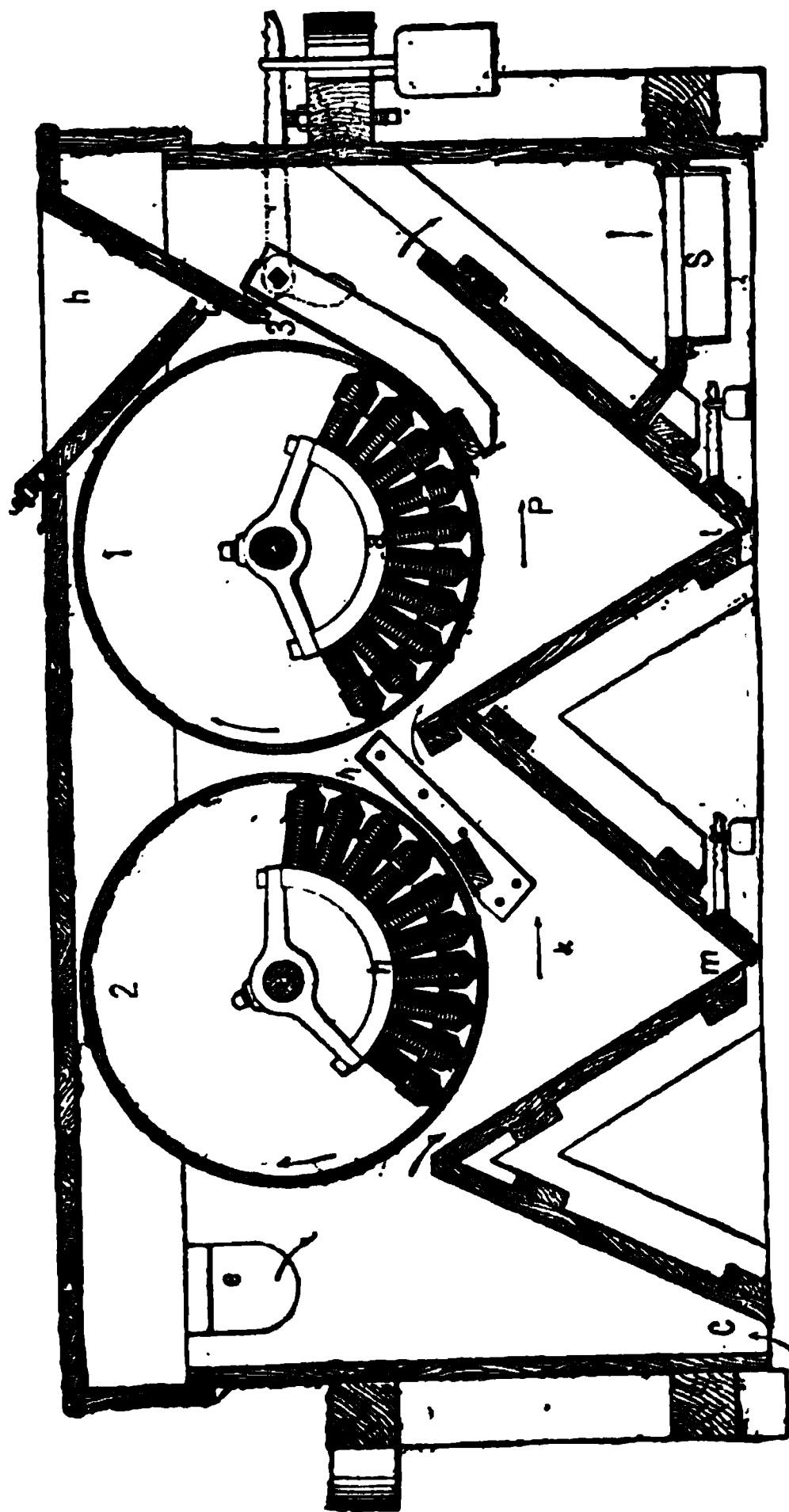


FIG. 270.—THE MONARCH MAGNETIC ORE SEPARATOR.

delivered to the machine from an ore pocket or storage-bin, provided with means for regulating the flow of ore so that when the machine is in operation the hopper is kept always full. Other

openings are provided for the discharge, at *t* of tailings, at *m* of middlings, and at *c* of concentrate; also at *e* for allowing free ingress of air to the chest at that point, and at *s* where a powerful exhaust fan is connected. The openings at *t* and *m* are kept sealed against ingress of air, at those points by means of the hinged and weighted valves, *vv*, which discharge the products from the hoppers, *p* and *k*, continuously, and in the same proportion as received from above, when a sufficient weight has accumulated upon the inside to cause the contents of the hoppers to leak by the valves.

When the machine is in operation the brass drums, 1 and 2, revolve on shafts, *i* and *j*, in the direction of the arrows, the magnets and shafts being stationary. The magnets are so constructed that the poles alternate, so that when the ore passes from hopper, *h*, along apron, 3, it comes under the influence of the magnet, and is picked up and firmly held against the drum; and as the drum revolves the ore is forced along past a succession of alternating poles, so that the magnetic particles take on a rotating or tumbling motion, allowing the non-magnetic gangue which may be entangled to be thrown off into hopper, *p*, while the magnetic portion is carried on and transferred to drum, 2; this drum revolving at a higher speed than the other throws off the less magnetic portion of the ore, this product being termed middlings, while the refined ore is carried to the end of the magnetic field, and delivered at *c*. The middlings consist of particles of magnetite having small pieces of rock or other foreign substance attached, and the proper regulation of this product is one of the important features of the invention; in fact, in some cases being vitally so, as in the case of the sand ore, where the foreign substance is titanium.

An improvement in the magnets has lately been made by Mr. Porter which gives a uniform magnetic field outside the drums, so that as the ore turns over on the first drum it not only allows the gangue to be expelled, but the richer portions of the ore get close up to the drum, while the leaner portion works to the outside of the stream, and this relative position of the particles being maintained during the transfer to second drum, the less magnetic material (middlings) is the more readily thrown off. A very important saving in the crushing of rock ore can be made

RESULTS OBTAINED BY MAGNETIC SEPARATION. 471

by this perfect control of the middlings. For instance, if the ore contained 5 per cent. of phosphorus, if there were only two products, concentrate and tailings, it might be necessary to crush the whole of the material to 16- or 20-mesh to get the iron sufficiently free from the rock (as the rock, in magnetic ores invariably carries the phosphorus); but if separated by the Monarch it could be taken, say at 6- or 8-mesh, when a large percentage of the pure iron could be recovered, and much to the worthless rock discarded, the middlings, representing probably 15 to 25 per cent. of the whole, alone requiring further crushing, not only saving the cost of crushing, but the even more objectionable feature of very fine ore. Consequently, by regulating the speed of the second drum, the concentrate can be brought to any degree of purity required—the greater the speed of drum the larger the percentage of middlings thrown off.

Space will not permit more than to draw attention to the great importance of this process in the treatment of zinc, silver, gold, tin, and other ores where magnetic ore may be present, or, indeed, any form of iron capable of being made magnetic by roasting.

The following are the results of a trial of this machine upon the ferriferous sea sand of the St. Lawrence, and show the analyses of the ore before and after concentration as well the weight of the various products :—

ST. LAWRENCE SEA SANDS.

No.		Iron.	Titanium.	Percentage of Total Weight.
1	Crude . . .	59'32	11'51	—
	Concentrates . .	69'40	2'37	52'50
	Middlings . . .	59'93	11'80	3'75
	Tailings . . .	47'68*	23'42	43'75
2	Crude . . .	59'32	11'51	—
	Concentrates . .	69'75	2'69	51'87
	Middlings . . .	59'98	11'97	1'87
	Tailings . . .	—	—	46'26
3	Crude . . .	55'20	4'50	—
	Concentrates . .	70'75	1'50	51'00
	Middlings . . .	56'50	11'69	0'75
	Tailings . . .	—	—	48'25

* Non-magnetic iron.

POWER REQUIRED TO DRIVE CRUSHING MILLS.—The amount of water power available at or near a mine will often decide the size of the mill to be erected. In any case, whether the mill is to be driven by water, steam, or electricity, one of the important points is the horse-power which it will take to drive it, and the results in tons treated, which may be reasonably expected from the expenditure of that power.

The following tables will enable an approximate estimate to be formed on these matters, and also show the power required to drive each of a standard type of machine, from which that necessary to work a number of the same machines can be calculated :—

POWER REQUIRED FOR A 10-STAMP WET CRUSHING GOLD MILL.

1 "Blake" rock breaker, No. 2	=	6	horse-power.
2 ore feeders	=	0	"
10 stamps, 750 lb., 90 drops	=	12	"
4 Frue vanner concentrators	=	2	"
1 grinding pan, 3 ft. diameter	=	3	"
1 settler	=	3	"
Friction	=	4	"
		<hr/>	"
Total	=	30	"

The above form of mill is capable of working 15 to 18 tons per day of 24 hours.

POWER REQUIRED FOR A 20-STAMP WET CRUSHING GOLD MILL.

1 "Blake" rock breaker, No. 2	=	6	horse-power.
4 ore feeders	=	0	"
20 stamps, 750 lb., 90 drops	=	23	"
8 Frue vanner concentrators	=	4	"
1 grinding pan, 8 ft. diameter	=	3	"
1 settler	=	3	"
Friction	=	7	"
		<hr/>	"
Total	=	46	"

The above power is capable of working 35 to 40 tons of ore per day of 24 hours.

POWER AND WATER REQUIRED FOR VARIOUS MILLS. 473

POWER REQUIRED FOR A 10-STAMP WET CRUSHING SILVER MILL.

1 "Blake" rock breaker, No. 2	=	6 horse-power.
2 ore feeders	=	0 „
10 stamps, 750 lb., 90 drops	=	12 „
6 grinding pans, 5 ft. diameter	=	30 „
3 settlers, 8 ft. diameter	=	9 „
Friction	=	7 „
<hr/>		
Total	=	64 „

The above power is capable of working 18 to 20 tons of ore per day of 24 hours.

POWER REQUIRED FOR A 20-STAMP WET CRUSHING SILVER MILL.

1 "Blake" rock breaker, No. 2	=	6 horse-power.
4 ore-feeders	=	0 „
20 stamps, 750 lb., 90 drops	=	23 „
12 grinding pans, 5 ft. diameter	=	60 „
6 settlers, 8 ft. diameter	=	18 „
Friction	=	13 „
<hr/>		
Total	=	120 „

The above power is capable of working 40 tons of ore per day of 24 hours.

Allowance is made for grinding in the pans in both of the above cases.

POWER REQUIRED FOR A 10-STAMP DRY CRUSHING SILVER MILL.

1 "Blake" rock breaker, No. 2	=	6 horse-power.
2 ore-feeders	=	0 „
10 stamps, 750 lb., 90 drops	=	12 „
1 "Howell-White" furnace, 40 in.	=	4 „
4 amalgamating pans, 5 ft. diameter	=	8 „
2 settlers, 8 ft. diameter	=	6 „
Friction	=	9 „
<hr/>		
Total	=	45 „

WATER REQUIRED FOR A QUARTZ MILL.

The quantity of water required to work either gold or silver ores by wet battery process is generally estimated as follows :—

For boiler, $7\frac{1}{2}$ galls. per horse-power per hour.

For each stamp, 72 galls. per hour.

For each pan, 120 galls. per hour.

For each settler, 60 galls. per hour.

Frue vanner, about 90 galls. of fresh water.

If the water used in the battery, pans, and settlers be run into settling tanks it can be re-used with a loss of about 25 per cent.

BELTING.—At the commencement of operations with a new mill, one of the most frequent sources of stoppage and discord will be due to the stretching of the belts. It will, indeed, take some considerable time for them to attain their final fixed length beyond which they will not stretch, and until this point is reached it is better to make the joints with screw fastenings, which can be readily undone and refixed, instead of the more permanent lacing, which can be finally adopted.

Leather belts are useless in wet situations, where indiarubber must be used. With a given tension a leather belt will transmit 30 per cent. more power when the grain or smooth side of the leather is turned next the pulley than when the flesh side is in contact with it. The belts should be kept soft and pliable by the application of tallow and neatsfoot or liver oil, with a little resin, when they become hard and dry. Their adhesion is greater on polished than on rough pulleys, and is about 50 per cent. greater on a leather-covered one than on a polished iron pulley.

The width of the belt should be determined by the strain to which it will be exposed, as the question of slipping is not affected by that of width. Long belts are more effective than short ones, and the slack of the belt should always be uppermost. Vertical belts depend entirely upon their tension, which the weight of the belt does not increase, as is the case with belts more or less horizontal.

At a velocity of 1000 ft. per minute a single belt, 1 in. wide, will transmit 1 horse-power, and a double belt will do the same at 700 ft. per minute; though when it is a long one, and running over large pulleys, it may be calculated to give 1 horse-power at the lower speed of 500 ft. per minute.

The strain which a good average leather belt may be calculated

to withstand is 350 lb. per square inch of section ; and at a speed of 1000 ft. per minute a section of 0·2 of a square inch will be required for each horse-power when the belt runs over a wooden drum. For smooth iron pulleys this must be increased to 0·4 of a square inch for each horse-power.

It must be remembered that grease and animal oils are ruinous to indiarubber belts, which when they show a tendency to slip should be smeared with boiled linseed oil on the inside, over which fine powdered chalk may be sprinkled.

The following rules will be found useful for various calculations relative to belting and pulleys :—

To Find the Length of Belts.—Add together the diameter of the two pulleys, multiply by $3\frac{1}{8}$, and divide the product by 2. To the quotient add twice the distance between the centres of the shafts and the product will be the required length. Allowance must be made for the length of the lap of the joint.

To Calculate the Power of Belting.—The horse-power of any belt equals its velocity per minute in feet multiplied by its width in inches, and divided by 1000 for single, or by 700 for double belts.

The basis of this calculation is that 1 horse-power is transmitted by a single belt 1 in. wide travelling at a speed of 1000 ft. per minute, or a double belt of the same width at a speed of 700 ft. per minute.

To Find the Speed of Pulleys.—(a) When the diameter of the driven pulley is given to find the number of its revolutions :—Multiply the diameter of the driver by the number of its revolutions, and divide the product by the diameter of the driven. The quotient will be the number of revolutions of the driven. (b) To find the diameter of the driver to give a fixed number of revolutions per minute when the diameter and speed of the driving pulley is known :—Multiply the diameter of the driver by the number of its revolutions and divide the product by the number of revolutions desired for the driver. The quotient will be the diameter necessary for the latter. (c) To ascertain the diameter of the driver :—Multiply the diameter of the driven by the number of revolutions desired and divide the product by the revolutions of the driver. The quotient will be the diameter of the driver.

CHAPTER XXVII.*

ELECTRICITY AS A MOTIVE POWER FOR MINING MACHINERY.

Advantages of Electricity—Electrical Terms and Units—Efficiency of Electrical Transmission—Electrical Horse-power—Examples of Electrical Transmission—Dynamo and Electromotor—Application of Electricity to Mining Machinery—Electric Mining Hoist—Electric Mining Pump—Electric Drilling Machine—Electric Traction—Cost of Electric Traction Plant.

ADVANTAGES OF ELECTRICITY AS MOTIVE POWER.—The recent advances in the science of electricity have opened up an immense field for its application as a motive power in mining and its associated industries.

The prohibitive cost of fuel for steam, and the want of a convenient supply of water, has been the cause of the failure of many a mining undertaking, but now the situation of a mine as regards its close proximity to water-power is no longer of such vital importance, seeing that the power of a river, even though 100 miles away, can be utilised by means of electricity for all the mill work as well as for the pumping and hauling at a mine which otherwise would be practically unworkable.

An instance in point is that of the Sheba Mine in South Africa, to which a 50 horse-power hauling plant has recently been sent out by the Brush Company. In this case the original power is taken by means of turbines from a river some 3 miles away from the mines, converted into electricity by means of dynamos and conveyed by a double insulated line of copper wires to the shaft, where it is reconverted into motive force and utilised for winding

* Some of the information given in this chapter originally appeared in an article written by myself on the same subject in the *Mining Journal* of June 11th, 1892.

and hauling from the mine. The useful effect is equal to 60 per cent. of the original water-power. And how is this result obtained, and what is this new motive force?

Practically, there is no definition of electricity, for up to this date, although great progress has been made in its application, no one has actually found out and determined what this subtle force is. All that can be done, therefore, is to point out some of the rules which regulate its use, and draw a parallel between it and one of the other sources of power with which we are more intimately acquainted.

The other science which will best serve as a familiar illustration of electricity is that of hydraulics, and the following arrangement is possibly the best for the purpose of explaining the connection and relation between the dynamo or generator of electricity and the electromotor or machine by means of which the electricity is reconverted into motive power. Underneath the streets of London and some other large cities are the high-pressure hydraulic mains, and through these pass the water which has been accumulated under enormous pressure, and which is used for the purpose of driving various motors and working hydraulic lifts in the city. The pumping station represents the dynamo or generating electric station; the hydraulic mains, the conducting wires; the water, the electric current; and the lifts or water-engines, the electromotor. It is evident that the power given out by the water motors bears some relation to that employed to accumulate it under pressure, and depends upon the quantity and pressure supplied, which again is modified by the length and diameter of the conveying pipes, as well as by the resistance offered by the pipes to the flow of water.

An electric installation is subject to almost equivalent conditions. The power given out by the motor is a certain percentage of that absorbed by the dynamo, and this is subject to modification by the electric pressure or electromotive force (measured in "volts" instead of pounds per square inch), by the quantity of electricity (measured in ampères instead of gallons), and the resistance offered by the length, size, and quality of the connecting wires (measured in ohms), which represent the friction of the water in the pipes.

The "volt," or unit of electric pressure, is sometimes spoken of

as electromotive force, or E.M.F., and is that amount of pressure which is sufficient to cause a current of 1 ampère to flow through a wire whose resistance is 1 ohm. The volt, therefore, is the difference of potential between any two points whether between the wires of the same system, between one wire and the ground, or between the wires of one system and those of another. In the case of a battery it is the difference of potential between the two poles. An ordinary Daniell's cell newly made up has an E.M.F. of 1.072 volt; a Leclanché cell, as used for electric bells and household use, of $1\frac{1}{2}$ volt; and a bichromate cell, familiar from its bottle-shaped form, has an E.M.F. of nearly 2 volts. Recently some experiments were made at the Crystal Palace with currents having a pressure or E.M.F. of 130,000 volts. The "ohm" is the unit of resistance, and is that offered by a column of mercury 1 square millimetre in section and 106 centimetres long. A copper wire, 1000 ft. long and $\frac{1}{100}$ th in diameter will, if the metal be nearly pure, offer a resistance of 1.0068 ohms at a temperature of 60 degs. Fahr., while a wire of German silver only 36 in. long and $\frac{1}{200}$ th diameter will offer a resistance of 1.12 ohm.

The term "ampère" expresses the unit of current, and it is the amount which a pressure of one volt can force through a resistance of one ohm while the "Coulomb" is the expression of quantity or flow of one ampère in one second.

The ampère is obtained by the formula :—

$$\frac{\text{Volts}}{\text{Ohms}} \text{ or } \frac{E}{R} = \text{Ampères.}$$

The table on opposite page gives the various electrical units, their symbols, derivation, and value :—

The practical question, however, with which mining men are especially interested is that of horse-power, and how to arrive at the mechanical effect which may result from the use of electricity. The unit of electric power is termed the "Watt," and is the rate of doing work either usefully, as in electric light and the conversion of electricity into mechanical motion, or wastefully in heating the connecting wires and the dynamo and motor. The "Watt" is the product of volts \times ampères, and each "Watt" is equiva-

ELECTRICAL UNITS * (MUNRO AND JAMIESON).

Unit.	Symbol.	Name.	Derivation.	Value.	
				C. G. S.	Equivalent.
E. M. F.	E	Volt	Ampère × Ohm	10^8	0.926 standard Daniell cell.
Resistance	R	Ohm	Volt ÷ Ampère	10^9	106 cm. mercury 1 sq. mm. section at 0° Cent.
Current	C	Ampère	Volt ÷ Ohm	10^1	{ 0.000105 gramme of hydrogen liber- ated per second. 2.5 knots of D.U.S. cable.
Quantity	Q	Coulomb	Ampère per second	10^1	
Capacity	K	Farad	Coulomb ÷ Volt	10^9	
"	K	Microfarad	1 millionth Farad	10^{15}	
Power	P	Watt	Volt × Ampère	10^7	0.0013405 or $\frac{1}{746}$ HP.
Work	{	Joule	Volt × Coulomb	10^7	0.7373 ft.-lb. 0.238 caloric.
Heat			Amp. ² × Sec. & Ohm	10^7	

C. G. S. system is made up of the fundamental units: centimetre for length, the gramme for mass, and the second for time.

lent to 44.2359 ft.-lb., or 1.746th of an electrical horse-power. To arrive at the theoretical horse-power which may be expected from any known current of electricity, it is necessary to know the current in ampères, and the pressure or E.M.F. in volts, both of which may be obtained by means of instruments called ammeters and voltmeters. By multiplying together the readings obtained from these instruments and dividing the product by 746, we have at once the equivalent force of the current in horse-power. Thus

$\frac{C \times E}{746} = \text{horse-power.}$ For instance, if a dynamo or set of batteries is giving off a current of 112 volts and 20 ampères as read by the meters, then the horse-power is $112 \times 20 \div 746 = 3$ horse-power.

If the number of watts only is given, then the horse-power is $\frac{\text{watts}}{746} = \text{horse-power.}$ In making electrical calculations as to the useful effect which will probably be obtained it is, of course, necessary to make ample allowance for losses from various causes,

* "Pocket Book for Miners and Metallurgists," by F. Danvers Power. Crosby Lockwood and Son.

and these may amount to about 40 per cent. of the original power, made up as in the following case :—

A mine is so situated that it cannot be worked on account of the cost of the fuel and its transport, nor is water-power available on the spot. A river flows about a mile away, and from this 100 horse-power can be obtained by means of a turbine or water-wheel. It is proposed to utilise this power for the working of the mine, and the following will be the approximate effective results obtained :—Indicated horse-power at turbine, 100.

Less 10 per cent. loss in gear	.	.	.	.	90
„	„	dynamo	.	.	9 81
„	„	connecting wires	.	.	8.1 72.9
„	„	electro motor	.	.	7.2 65.7
„	„	gear of motor	.	.	5.7

HP. delivered at mine = 60

Therefore the efficiency of the system will be . . . 60 per cent.

and the losses of the system will be . . . 40 „

This result will compare very favourably with those obtainable by any other system, such as the cable and compressed air, while the erection of a mile or more of telegraph line is simplicity itself as compared with the cost and expense of putting up a travelling cable or laying pipes for compressed air.

A strong well-insulated cable can be carried over the roughest ground on stout poles, well stayed, and provided with lightning-conductors, with about 35 poles or spans per mile, the cost of the cables being £60 per mile of cable.

Again, to take another instance, we have a source of water-power capable of delivering 50 horse-power to the pulley of the generating dynamo, at a distance of $2\frac{1}{2}$ miles from a mill or mine, where we have 10 stamps requiring $2\frac{1}{2}$ horse-power each, and have selected a safe working E.M.F. and current, which will entail a loss not exceeding 10 per cent. in the cables.

The electrical efficiency of such a system would be about 64 per cent., or 32 horse-power given at the pulley of the motor. In addition, sufficient power could be spared to run 5 or 6 arc lamps, which would effectively light an area of 4800 ft.; or 12 stamps of $2\frac{1}{2}$ horse-power could be driven instead of the 10.

The cost of such a plant (f.o.b.) in London would be about

£125 per stamp of $2\frac{1}{2}$ horse-power, or £50 per horsepower. This does not include the freight, cost of fixing, and engineering necessary for the proper delivery of the water to the turbine, all of which must depend upon circumstances; but the comparison of the cost with that of steam-power, taking the running cost of the two systems into consideration, will show what an enormous field there is for the application of the combination of water-power with the electrical transmission of the same.

The loss in the connecting wires of an electric installation depends upon the material and size of the wires adopted, and also upon the perfection of the insulation of the line. Copper conductors are almost exclusively used, and as the resistance they offer depends upon their diameter, it pays best to have them of large section and pure material. The line of wire is always double, and the present methods of insulation are sufficiently perfect to prevent any appreciable loss from this cause.

The following table will give the horse-power when the number of watts is known:—

Watts (C × E) H.P. = 746 Watts.

Watts.	HP.	Watts.	HP.	Watts.	HP.	Watts.	HP.
		17,158 =	23	36,554 =	49	55,950 =	75
93.25 =	$\frac{1}{4}$	17,904 „	24	37,300 „	50	56,696 „	76
186.5 „	$\frac{1}{2}$	18,650 „	25	38,046 „	51	57,442 „	77
373 „	$\frac{3}{4}$	19,396 „	26	38,792 „	52	58,188 „	78
746 „	1	20,142 „	27	39,538 „	53	58,934 „	79
1,492 „	2	20,888 „	28	40,284 „	54	59,680 „	80
2,238 „	3	21,634 „	29	41,030 „	55	60,426 „	81
2,964 „	4	22,380 „	30	41,776 „	56	61,172 „	82
3,730 „	5	23,126 „	31	42,522 „	57	61,918 „	83
4,476 „	6	23,872 „	32	43,268 „	58	62,664 „	84
5,222 „	7	24,618 „	33	44,014 „	59	63,410 „	85
5,968 „	8	25,364 „	34	44,760 „	60	64,156 „	86
6,714 „	9	26,110 „	35	45,506 „	61	64,902 „	87
7,460 „	10	26,856 „	36	46,252 „	62	65,648 „	88
8,206 „	11	27,602 „	37	46,998 „	63	66,394 „	89
8,952 „	12	28,348 „	38	47,744 „	64	67,140 „	90
9,698 „	13	29,094 „	39	48,490 „	65	67,886 „	91
10,444 „	14	29,840 „	40	49,236 „	66	68,632 „	92
11,190 „	15	30,589 „	41	49,982 „	67	69,378 „	93
11,936 „	16	31,332 „	42	50,728 „	68	70,124 „	94
12,682 „	17	32,078 „	43	51,474 „	69	70,870 „	95
13,428 „	18	32,824 „	44	52,220 „	70	71,616 „	96
14,174 „	19	33,570 „	45	52,966 „	71	72,362 „	97
14,920 „	20	34,316 „	46	53,712 „	72	73,108 „	98
15,666 „	21	35,062 „	47	54,451 „	73	73,854 „	99
16,412 „	22	35,808 „	48	55,204 „	74	74,600 „	100

The distance which separates the motor from the generator has, of course, the effect of increasing the resistance offered to the passage of the current ; but by employing copper conductors of adequate size this loss by resistance may be kept within reasonable limits, even when the distance is abnormally large, greater than will ever be required in mining. The greatest number of miles to which a useful current has hitherto been conveyed is 110, and in this case the efficiency of the system was as high as 72 per cent. The generating plant is situated at Lauffen on the Neckar, in Germany, and the current is conveyed to the city of Frankfort, a distance of 110 miles. The result actually obtained is that, when 113 horse-power are taken from the river, the energy received at Frankfort is 81 horse-power, thus showing an efficiency, after deducting all possible losses, of $72\frac{1}{8}$ per cent.

Mining presents a fair field for the employment of this new motive force, and already it has been employed for pumping, winding, underground hauling, coal cutting, and rock drilling ; and, doubtless, as the number of appliances increase, so also will many mines be brought into a paying condition which, hitherto, because of their situation, they have never arrived at.

The question of the erection of an electric plant is not one which should present any difficulty to the well-trained mining man. The original motive power, when steam is not used, is either a turbine or a water wheel, and with either of these appliances all engineers are familiar. The generating dynamo, or dynamos, according to the size of the installation, are connected with the turbine by means of suitable belting, the great point being to drive the electric plant at a fixed and constant speed in order that the strength of the current may not vary. The Pelton water wheel, described in Chapter I., is especially adapted to this purpose, and may be connected direct to the shaft of the dynamo, as in fig. 271, which represents a 125-horse-power Brush dynamo so arranged. In the dynamo room will be found the various gauges for indicating the speed of the machines and the strength of the current in ampères and volts, and also a switch board or appliance for the connection of the wires from the dynamo with those of the line, or with any apparatus, a description of which will be found on page 505.

FIG. 271. — PELTON WHEEL AND DYNAMO COMBINED.

The line wires are supported on posts in the same manner as telegraph wires, and terminate in the motor room at the mine. There they are connected to another switch board, and pass on to the motor, the speed of which is reduced, either by gearing or belting, down to that required for the end in view. When it is desired either to slacken the speed or to stop or reverse the machine, the current is not abruptly cut off, but by means of the switch board a number of iron wire resistance coils are interposed in the circuit, and these, by increasing the resistance offered to the passage of the current, weaken it to a corresponding extent, and so bring it under control, just as a steam engine is controlled by the closing of a valve. In short, the whole arrangement is so simple that an ordinary mechanic can be safely entrusted with the care of it.

TRANSMISSION OF POWER.—In America electricity is now being largely utilised for the transmission of power, and many of the mills on the Comstock Lode are driven by its means. As an example of the general arrangement adopted in the States, the following description of the plant at the Dalmatia Mine, in El Dorado County, California, will be interesting :—

The power station is located on Rock Creek, some 1500 ft. below the mine and mill, and two miles distant in a straight line.

The plant consists of an 8-ft. Pelton wheel, which, running under a head of 110 ft. at 100 revolutions, with a $5\frac{1}{2}$ -in. nozzle, has a maximum capacity of 130 horse-power. To this wheel is connected a 100 horse-power constant current Brush generator—30 ampères—speeded at 900 revolutions, the current from which is carried to the mill through a single insulated copper wire, No. 3, B. and S. gauge, the return being made by a wire of the same size, making a 4-mile circuit. The power from the generator is communicated to the countershaft of the mill by a 70 horse-power motor running at 950 revolutions.

The machinery operated consists of three Huntington mills, a 10-stamp battery, and a rock breaker. The Pelton wheel under these conditions shows an efficiency of 86 per cent., while about 75 per cent. of the power thus generated is available for duty at the mill. Sufficient power is taken from the main circuit to run

60 incandescent lamps for lighting the works, office, and residence of the manager.

The equipment has now been in constant operation some 2 years and is a most pronounced success, no interruption to the service of any moment having occurred during this time. The mill named is handling an average of 4000 tons of ore per month, effecting a saving of some 60 per cent. over the former method of working by steam-power, while the cost of maintenance is about as 6 to 1 in favour of electricity.

An extension of this line has recently been made to the St. Lawrence mill, similar in character to the Dalmatia, located 3 miles from the latter and 5 miles from the water wheel station.

This mill is run by a 70 horse-power Keith motor, and the service of the plant is reported as entirely reliable and in every way satisfactory, the percentage of power over the longer circuit being but little less than to the mill first named.

Pumping and hoisting plants are now under construction to be operated by electric power from the same source, and it is the intention of the syndicate to put in additional wheels and generating machinery up to the full capacity of their water supply—estimated at 1500 horse-power—for the purpose of furnishing power to other mines in the vicinity.

There is no need to multiply the descriptions of the plants already erected in all parts of the world. We will therefore proceed to consider the machinery by which this force is created, transmitted, and reconverted into power.

DYNAMOS AND MOTORS.—The theory and practice of the construction of dynamos and electro-motors hardly comes within the scope of a work on mining machinery, so that I must refer my readers to the many excellent works* upon the subject should they desire to make a study of these machines, and also to Chapter XXVIII. on Electric Lighting and Blasting, which contains much additional information.

I will simply illustrate one of the many types of dynamos, in order that the nomenclature of the parts may be made familiar to

* Amongst others may be mentioned those by J. W. Urquhart, published by Crosby Lockwood and Son.

those who have not already had practical experience of them; and as most dynamos will work equally well as motors, the same description will apply to both machines.

The dynamo is a machine for converting mechanical force into electric energy, and when used as a motor it reconverts the electric energy into mechanical force with some amount of loss, though small, as described on page 480. The machine itself consists of a cast-iron bed-plate, B, fig. 272, on which there are three standards with bearings for supporting the shaft, E E. Upon the shaft is keyed an armature, A, consisting of a series of coils of copper wire, the ends of which are connected with the plates of the commuta-



FIG. 272.—DYNAMO.

tor, C. The armature is caused to revolve by means of the driving pulley, P, at a high rate of speed between the poles of a powerful electro-magnet, M, the result being that a current of electricity is generated in the coils of the armature, passes thence to the commutator, C, and is collected by means of the brushes, B, from which it is conducted to the terminals of the machine, and thence to the lamps or motor. A fuller description of a dynamo will be found in Chapter XXVIII.

This particular type of machine is furnished with a third bearing, in order to better accommodate a loose pulley as well as the

ordinary fast pulley. It is also fitted with a belt striking gear or band fork under the control of the lever, s, which enables the attendant to put the armature into motion or stop it without reference to the engine.

The outward form of the dynamo varies considerably according to the different makers, the type of armature and winding employed; but the following are the general particulars and prices of these machines adapted for use in mining, whether for lighting or power purposes. See next page.

If the terminals of a dynamo in motion be connected with those of a dynamo at rest, the current from the active machine will traverse the circuit of the idle one and cause the armature to revolve, converting it into an electro-motor; and so we have the whole system of the electrical transmission of power exemplified, the efficiency of which is explained on page 480.

It will be seen that as regards erection the machine presents no difficulty; it is simply bolted down to a firm foundation and driven at a definite rate of speed by a well-governed motor whether steam, water, gas, or oil, and at this speed certain known results can be absolutely relied upon.

The Goolden Mining Motor.—The forms of electro-motors for use on the surface are very varied, owing to the differences in the construction of the field magnets and armatures adopted by various makers, and also to the great variety of uses to which this form of machine is applied. For underground use, however, as well as for use as the motive power of a stamp battery, various difficulties are met with which necessitate special precautions.

One of the principal of these is the very rough conditions and dirty situations in which the motors have to be used, and a further difficulty in coal mines is the danger that occasionally arises from the presence of explosive gases. For ordinary purposes, even in coal mines, it may be safely assumed that the motor will not be working normally in an explosive atmosphere, and it is therefore sufficient to carry out the arrangement, patented some years ago by Messrs. Goolden and Co., of enclosing the whole armature and brushes in air-tight and dirt-tight coverings. These coverings would be sufficient to exclude an explosive mixture for many hours, and before such mixture found its way into the neighbour-

Output in Watts.	Approximate Output in Horse-power.	Approximate No. of 60 W. Lamps.	Approximate Speed.	Horse- power on Belt.	Length.	Width.	Height.	Weight.	Price for Shunt Wound.	Spare Armature.	Slide Rails.
1,000	1½	16	1,500	2	ft. 2 in. 4	ft. 1 in. 10	ft. 1 in. 8	cwt. 3½	£ 26	£ 12	£ 1
2,000	2½	32	1,500	3½	ft. 2 in. 6	ft. 1 in. 10	ft. 1 in. 8	cwt. 4½	£ 35	£ 16	£ 1
3,500	4½	58	1,500	6½	ft. 2 in. 8	ft. 1 in. 11	ft. 1 in. 8	cwt. 6	£ 48	£ 20	£ 2
5,000	6½	83	1,200	8	ft. 3 in. 8½	ft. 1 in. 5	ft. 2 in. 2	cwt. 8	£ 65	£ 28	£ 3
8,500	11½	140	1,100	13½	ft. 3 in. 8½	ft. 1 in. 5	ft. 2 in. 2	cwt. 10	£ 86	£ 35	£ 3
11,000	15	180	1,000	17	ft. 3 in. 9½	ft. 1 in. 6	ft. 2 in. 2½	cwt. 12	£ 110	£ 38	£ 4
14,000	19	230	900	21½	ft. 4 in. 0½	ft. 1 in. 7	ft. 2 in. 5	cwt. 16	£ 122	£ 42	£ 4
18,000	24	300	800	28	ft. 4 in. 6	ft. 1 in. 7	ft. 2 in. 6	cwt. 22	£ 149	£ 50	£ 5
21,000	28	350	750	33	ft. 4 in. 7	ft. 1 in. 9	ft. 2 in. 7	cwt. 24	£ 160	£ 59	£ 5
24,000	32	400	700	37	ft. 4 in. 9	ft. 1 in. 10	ft. 2 in. 8	cwt. 29	£ 178	£ 65	£ 5
30,000	40	500	650	45	ft. 5 in. 4	ft. 2 in. 2	ft. 2 in. 9	cwt. 33	£ 210	£ 76	£ 6
36,000	48½	600	600	55	ft. 5 in. 8	ft. 2 in. 6	ft. 3 in. 0	cwt. 38	£ 239	£ 87	£ 6
45,000	60	750	560	68	ft. 6 in. 8	ft. 2 in. 10	ft. 3 in. 4	cwt. 47	£ 280	£ 102	£ 8

hood of the armature or brushes, the condition of the atmosphere would have been noted by the attendant, and the current cut off. One form of the "Goolden" mining motor is shown in fig. 273, which embodies, besides the complete enclosing of the armature, various other important features. The construction of the armature is unusually strong, and the wires being keyed in every position, and insulated from the core and from one another by means of mica, a construction is arrived at which has enabled these machines to be used for driving hauling machinery, subject to great vibration and shocks by the use of gearing, thus doing away with belts, chains, and other forms of connection, all of which have been proved in practice to be unsuitable for working: at all events, in parts that are in any way portable, which should be the case with the bulk of mining work.

The enclosure of the armature has been supposed by some to be impossible, on the ground of the want of ventilation, and in the discussion on mining motors which took place some two years ago at Sheffield, at the meeting of the Mining Institute, several eminent electrical engineers, stated that, in their opinion, it was impossible to work a motor thus enclosed. It is sufficient to add that even on that date Messrs. Goolden were using motors working up to 30 or 40 horse-power with such enclosed armatures.

The frame and bed-plate of a Goolden mining motor are made

FIG. 273.—THE GOOLDEN MINING MOTOR.

of cast iron, the magnet bars being of the finest soft hammered scrap. The armature is built of the best Swedish annealed iron plates insulated from one another, all fitted by slotting to the spider, which is fitted by sunk keys to the Bessemer steel shaft.

The winding of the armature is of the special Gramme type, and the whole of the wire is driven by a special method of fibre driving horns, whereby the wires are fixed perfectly firm in position and cannot shift.

The commutator is of hard-drawn selected copper or special hard phosphor bronze, and is insulated with mica. It is mounted

by a method allowing nearly all the copper to be used, and giving an inch vertical depth of wear.

The brushes and brush-holders are of a special type admitting of their being easily set by inexperienced men, and so that the motor may be used for very rough work, without the brush jumping and so causing flashes.

The field-magnet coils are of the best insulated copper wire, removable, if necessary, and enclosed in a steel lagging as a protection from injury.

The armature brushes and commutator are enclosed in patent gas-tight covers, whereby any gas is prevented from coming into contact with the brushes and commutator, and so there is no fear of an explosion being caused by the sparking or flashing of the brushes even in fiery positions.

These covers also keep all dirt and dust from the running parts and protect the armature and commutator from damage in case of falls of the roof or other causes.

The terminals and connections are also enclosed in such a way that it is impossible, except intentionally, to touch any part carrying an electric current.

The following table gives the price and other particulars relative to this class of motor, which may be either series or shunt wound, or specially compounded on a method whereby good starting power is obtained, whilst the speed regulation is practically as good as in the case of a shunt wound motor :—

GOOLDEN MOTORS UP TO 1000 VOLTS. GRAMME ARMATURES.

Brake Horse-power.	Watts required.	Revolutions.	Maximum Volts Wound for.	Length.	Height.	Width.	Weight.	Price.
				ft. in.	ft. in.	ft. in.	cwt.	£
1½	1,250	1,500	180	2 4	1 10	1 8	3½	28
2½	2,500	1,500	250	2 6	1 10	1 8	4½	37
4½	4,200	1,500	300	2 8	1 11	1 8	6	48
6½	5,800	1,200	500	3 8½	1 5	2 2	8	65
11½	10,000	1,100	800	3 8½	1 5	2 2	10	86
15	12,800	1,000	900	3 9½	1 6	2 3	12	110
27	22,800	750	1,000	4 7	1 9	2 7	24	160

Electric Mining Hoist.—The illustration, fig. 274, shows the arrangement adopted by Messrs. Woodhouse and Rawson, Ltd., for attaching an electro-motor to a hoisting drum to be used for winding purposes exactly as steam is so employed. The motor, which runs at a speed of about 1000 revolutions per minute, is connected by means of spur gearing with the drum. The speed of the motor is controlled by an electric switch at one side, by means of which it can be varied by a single movement of the switch handle. Turning the handle to one notch will make the motor run slowly; through two notches, faster; and full

FIG. 274.—ELECTRIC MINING HOIST.

number of notches, at full speed; while turning the handle in the opposite direction will give similar rates of speed with opposite direction of rotation. In other words, the hoist is reversed. The gearing is all boxed in iron cases in order to protect it from dust and stray stones, while, for use underground in fiery mines, the commutator can be made on the safety principle which avoids all danger of explosion from sparking.

The drum is provided with a strap brake worked by a foot lever, so that the whole machine is immediately under the control of its driver. The efficiency of the electric motor when working under its full load is claimed to be over 90 per cent.—that is, that more than nine-tenths of the energy which is delivered to it in the

form of an electric current at the terminals of the motor are transformed to effective work at the armature pinion.

Electric Continuous Rope Hauling Machine.—From winding to hauling is but a short step, and fig. 275 represents an underground hauling engine of the "Goolden" type, consisting of a strong cast-iron bed-plate, carrying a dip pulley driven through two sets of gearing by means of a Goolden mining motor of the safety pattern.

The shafts are of Siemens-Martin steel, turned all over with feather keyways, and running in bearings lined with phosphor bronze liners with strong cast-iron caps.

The gearing is of cast iron with double helical teeth, the wheels



FIG. 275.—ELECTRO-MOTOR DRIVING A CONTINUOUS ROPE HAULING PLANT.

being turned and faced on the bosses, and have deep keyways slotted into them. The clip pulley is also of cast iron, turned and faced on the bosses, and securely keyed to the shaft, with independent clips giving great grip without damage to the rope.

The engine is started and stopped by a switch of the "Goolden" non-sparking type, whereby absolutely no spark is produced on breaking the circuit, the whole being enclosed in a strong gas-tight iron box, and when necessary means are provided for starting or stopping slowly.

In metalliferous mines there is of course no necessity for the safety gas protector. It is, however, extremely useful in keeping

all dust and dirt from the armature of the motor, and for this reason alone is worth retaining.

For main and tail hauling the arrangement is somewhat similar to that used for hoisting, except that two drums are employed driving through a clutch gear, by means of which either drum can

FIG. 276.—ELECTRIC MINING PUMP SHOWING ELECTRO-MOTOR.

be driven for drawing up either road, while the other is free for paying out cable.

The motors are connected by means of cables with the generating dynamo, situated at the mouth of the shaft or at the source of water-power.

Electric Mining Pumps.—All mining engineers are intimately acquainted with the use of pumps driven by steam or water,

whether on the surface or underground. Some of them have employed compressed air for this purpose, and now a rival of these motive forces has come into the field in the shape of the electric current, which because of the ease with which it can be conducted to the scene of operation in difficult places by means of flexible cables, is likely to come into very general use for the purpose of underground drainage.

FIG. 276A.—ELECTRIC MINING PUMP SHOWING 3-THROW PUMP.

The electric mine pump, such as is illustrated in fig. 276, is now at work under heads of over 600 ft., and its efficiency, as ascertained by careful independent tests, amounts in horse-power of water delivered to 75 per cent. of the brake power of the engine. The price of the insulated double cable connecting the dynamo to the motor of the pump is about £10 per 100 yards for the smaller sizes.

The pump shown in the drawing is a three-throw ram pump

driven through cast-iron gearing by an electric motor, the whole machine being mounted on a cast-iron bed of box pattern.

The pump cylinders are of cast iron fitted with phosphor bronze ram bushes, the rams being of cast iron or gun metal if specially ordered. The valves and seats are of brass of large size, and the shaft and countershafts are of steel, forged in one piece, running in bearings lined with adjustable phosphor bronze or gun metal bushes, fitted with syphon lubricators.

These pumps are made in the following standard size, of which the smaller ones may be run from lighting dynamos where they already exist :—

GOOLDEN ELECTRIC PUMPS.

Head of Water in Feet.	Gallons of Water per Hour.	Horse-power of Motor.	Price of Electric Pump complete.	Price of Dynamo suitable.	Horse-power required at Dynamo.	Horse-power at Belt.	Extra for enclosing the Motor.
			£ s.	£			£
200	1500	2·6	93 10	45	2·9	3·2	12 10
300	1500	4·0	125 0	60	4·6	5·2	14 0
500	1500	6·5	178 0	88	7·6	8·7	16 0
200	3000	5·2	156 0	85	6·1	7·0	16 0
300	3000	7·8	196 0	115	9·2	10·5	20 0
500	3000	13·2	244 0	146	15·4	17·5	22 0
200	5000	8·8	188 0	115	10·2	11·5	20 0
300	5000	13·2	220 0	146	15·4	17·5	22 0
500	5000	22·0	300 0	195	26·0	29·5	29 0
500	6000	26·0	360 0	220	31·3	35·5	33 0
800	6000	40·0	490 0	300	50·5	57·0	44 0

Electric Drilling Machinery.—An electro-motor can be readily attached to the rotary drills used for boring in coal and soft shale, and will make a hole of from $\frac{1}{2}$ -in. to $1\frac{3}{4}$ -in. diameter at the rate of from 6 to 15 in. per minute to a depth not exceeding 3 ft. 6 in. For boring in the hard rock usually met with in metalliferous mining, no electric drill has yet been manufactured which will compete with the ordinary air-driven rock drills, which, in addition to boring a hole at the same time, largely assist in the ventilation of the workings.

If electricity cannot be applied direct to the drill it can, however, be used with advantage in driving the air compressor, and will practically annihilate the distance separating the compressor from

the cheapest source of motive power—water. The difficulty and loss from leakage and friction, of conducting air in long lengths of piping from the compressor situated near a river to the mine, possibly a mile or more away, is overcome by placing the generating dynamo at the turbine and conducting the current any reasonable number of miles by cable to the motor at the compressor. The same current can be used for lighting or other purposes, and the mine both above and below ground rendered independent of steam and costly fuel.

All that is required is that the high speed of the motor should be reduced by a train of gearing to the comparatively low speed of an air compressor or other machine, and this in the case of a compressor is effected in the manner shown in fig. 114, where the motor is mounted between the two driving-wheels of an Ingersoll-Sergeant air compressor, and is supplied by electricity through the cables suspended from the roof.

ELECTRIC TRACTION.—Hitherto I have spoken of the use of electricity in its application as a motive power to stationary machines.

Soon after its introduction for this purpose, however, it became evident that it could be equally well used as a means of locomotion, and numerous experiments were made with this end in view, terminating by the construction of a short, narrow-gauge railway at Bushmills, in Ireland. This was quickly followed by various tramways, and still more recently by the electric railway running from the monument in London under the Thames to Stockwell, while on February 4th, 1893, the first full-gauge railway for running the usual heavy type of passenger coach was opened at Liverpool, where a line of overhead railway on the American system, having a length of seven miles, has been for some time past in course of construction.

Nor have the mining industries been behindhand in adopting this new means of traction, which can be obviously used to great advantage both on the surface and underground, especially where water-power is available for driving the generating dynamos.

The illustration, fig. 277, is from a photograph of a mining tramway recently erected by the Electric Construction Corporation, Limited, of London and Wolverhampton. The gauge is 2 ft.,



FIG. 277.—Electric Locomotive for Mining Purposes.

and the engine is capable of taking a load of 4 tons up a gradient of 1 in 19 at a speed of five miles an hour.

The current from the generating dynamo is carried through a bare copper wire suspended overhead from insulators, and contact between the engine and this is made by means of the arrangement shown on top of the engine, which rubs continually against the wire and adjusts itself by means of balance weights, to any variation in its height.

The current is controlled by the driver by means of switches, and after passing through the motor returns to the dynamo by means of the rails. As will be seen from the photograph the arrangement for hanging the overhead wire is of the simplest description, and could be carried out underground with great facility.

Perhaps in fiery collieries such an arrangement would not be admissible owing to the possibility of an occasional spark between the conducting wire and the engine contact maker; but in metalliferous mines this would be immaterial.

The engine can be easily reversed, and can be driven by any mechanic, while the erection of the plant demands no skilled attention beyond that which any mine manager who has studied his profession should be able to give to it.

A small electric locomotive for a 2-ft. guage, such as that shown in fig. 252, capable of working up to 9 horse-power with power to increase this for a short period at starting a train, or up a short length of steep gradient, would cost about £225.

The dynamo with the necessary measuring instruments and switches for supplying the current to the locomotive, would cost about £140, while a mile of bare copper conducting wire together with the necessary insulators, would cost £60—making a total of £425 for the electric plant.

When laying the road it would be necessary for the ordinary rails to be electrically jointed together by means of a length of copper wire across the fish-plates, so as to secure a complete metallic circuit for the return current through the locomotive wheels, and back along the rails to the dynamo.

If a number of locomotives are required to run upon the one line, the proportional cost of the dynamo and overhead conductors would be considerably reduced.

CHAPTER XXVIII.

ELECTRIC LIGHTING AND BLASTING.

Arc and Incandescent Systems—Dynamo for Lighting Purposes—Series Shunt and Compound Wound Machines—Erection of Dynamo—Conductor's Switchboard—Example of a Joint Arc and Incandescent System—Trial Run—Working Rules—The Arc Lamp—Incandescent Lamps—Electric Blasting.

ELECTRIC LIGHTING.—The use of electricity for lighting purposes is so well known that it need not be brought before mining men as a novelty. The point which concerns them more especially is how to erect the necessary machinery if they are called upon to do so. This has fallen to my lot on several occasions, and in giving an outline of the procedure, I avail myself to some extent of the printed instructions issued by the firm of Sautter, Harlé et C^{ie}, of Paris, whose dynamos and lamps, both arc and incandescent, I have erected and run successfully over a long period.

The two words "arc" and "incandescent" at once bring us face to face with two different systems of lighting, both of which have their merits, and both of which can be carried out from the same dynamo at the same time, provided that the dynamo is designed for that purpose.

Lighting by arc lamps is suitable for large, open spaces, by means of a few powerful lamps fixed at the head of tall poles. Incandescent lighting, on the contrary, is adapted to the illumination of the interior of mills, mines, and offices, by means of a large number of lamps of small power, say each equal to 16 candles, which can be put wherever they are required, and, once the line of insulated conducting wires is established, give no further trouble.

In the chapters devoted to electricity as a motive power, I have already referred in general terms to the construction of a dynamo, and in figs. 278 to 284 will be seen the various parts of an unmounted machine which, when put together, form a complete dynamo, as shown in fig. 282.

In fig. 278 will be seen the framework of the machine made of soft cast iron, and with the field-magnet coils in place. By unscrewing the two set pins seen on each side of cap of the dynamo

FIG. 278.—FRAMEWORK OF AN ELECTRIC LIGHT DYNAMO.

these coils can be removed ; but in that case great care must be taken to remake the connections exactly as they were found.

Fig. 279 is the armature, consisting of a large number of coils of insulated wire wound over a cylinder formed of soft iron wire. The ends of the coils are fastened to the radiating strips of copper, and these latter to the bars of the commutator, from which the current is collected by means of the brushes (fig. 280).

The brushes are fixed on a frame which can be turned to a certain extent in order to allow of their adjustment, which should lightly touch the commutator on a diametrical line slightly off the horizontal, as will be seen in the general view, fig. 282.

After the machine has been running continuously for some time, it becomes warm, and its electrical balance being disturbed it may be necessary to advance the brushes, which is done by unscrewing the set pin, the handle of which is seen, and turning the brush holder until a point is arrived at, where the sparking between the brushes and the commutator is reduced to a minimum. The frame is then fixed at this point by means of the set screw.

The armature revolves in the long bearings shown, and is driven by the pulley, fig. 281, keyed to its shaft. As the cap of

FIG. 280.—THE BRUSHES AND
BRUSH-HOLDER.

.

FIG. 279.—THE ARMATURE.

FIG. 281.—THE PULLEY.

the dynamo is removable, the whole machine can be readily unmounted for cleaning, and fitted together again with ease.

As the armature revolves between the poles of the field magnets, the small amount of residual magnetism of the iron excites a current of electricity in the coils of the armature, and this current, feeble at first, increases the magnetism of the poles, which in their turn excite an increased current, and so the machine after a very few revolutions attains its maximum. The power required to turn the armature increases likewise, and it is this mechanical power which is converted into electrical energy, and produces the

current required either for lighting purposes or for reconversion after transmission to a great distance into mechanical force.

I have said that the slight current induced in the armature by the first few revolutions passes through the field magnets and increases their magnetic intensity.

In some dynamos the whole of the current is allowed to pass through the field magnets. These are called series wound, and are especially used for supplying the current to a large number of

FIG. 282.—THE COMPLETE DYNAMO.

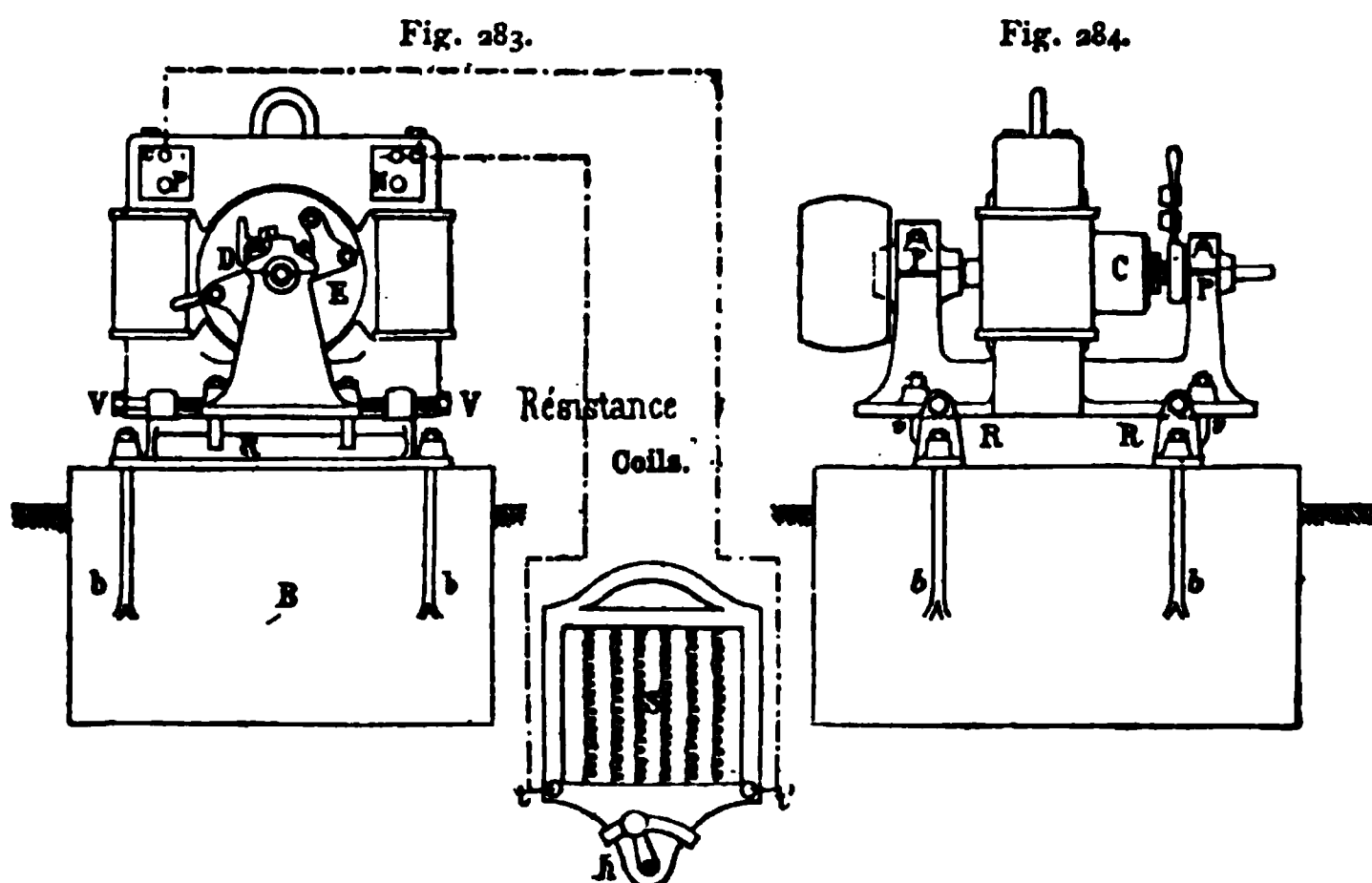
arc lamps arranged in series, by which is meant that the current passes through the whole of the lamps one after another.

In other cases only a portion of the current is allowed to pass through the field magnets of the dynamo, and the machine is then said to be shunt wound, and is adapted for the purpose of charging accumulators, though it may be also used with certain modifications for arc or incandescent lighting.

Lastly, we have the compound dynamo, the field magnets of which are so arranged that through a portion of them the whole of the current passes, while the other portion is shunt wound.

This class of dynamo is the one most generally useful, as it will supply both arc and incandescent lamps at the same time, which is exactly what is required in mining, when we have to provide for lighting the open spaces surrounding the surface works, as well as the interior of the mill and the mine.

As the compound shunt wound dynamo can be used for arc or for incandescent lighting singly or for both at the same time, and as the instructions for the erection of this type of dynamo will serve generally for that of any other, we will now consider how a combined lighting plant may be installed.



FIGS. 283 AND 284.—FOUNDATIONS FOR DYNAMO, END AND SIDE.

It is absolutely essential that a dynamo should be driven at a fixed, unvarying speed, so that if it is proposed to connect it by belt to a line of shafting which drives other machinery, the speed of that shaft must be uniform, and should not vary more than 3 per cent. If this regularity cannot be relied upon, then a special motor, either steam or water, must be supplied, and this motor must be provided with a sensitive governor. It may be connected direct to the shaft of the dynamo if the speed is high enough, or, as is more usual, by means of a belt. The belt must be just sufficiently tight as to avoid slipping, which would cause

the lamps to flicker, and yet not so tight as to cause the bearings to heat.

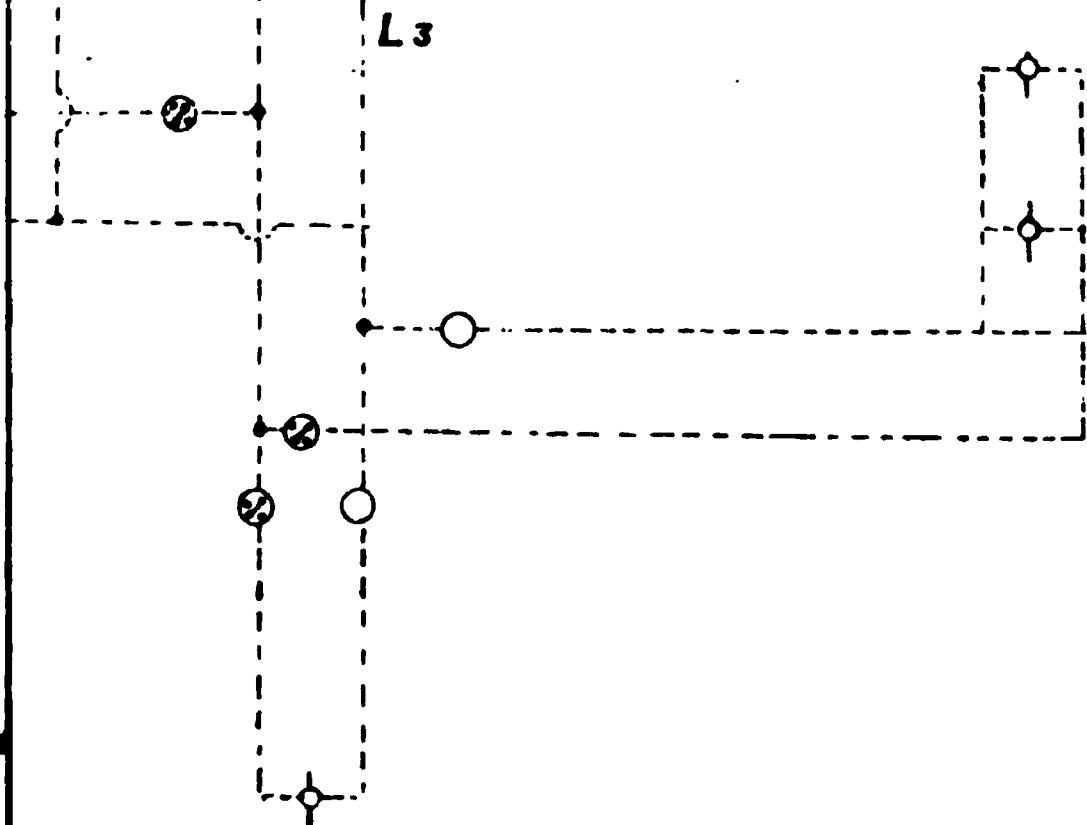
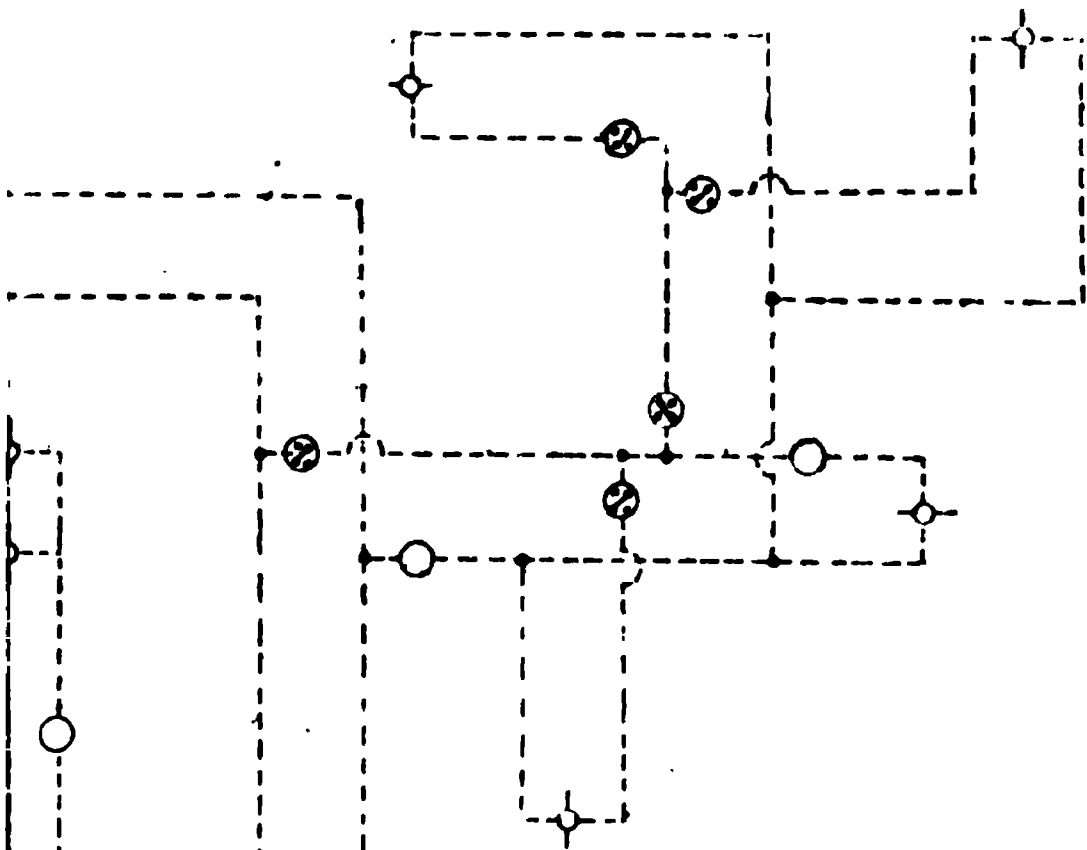
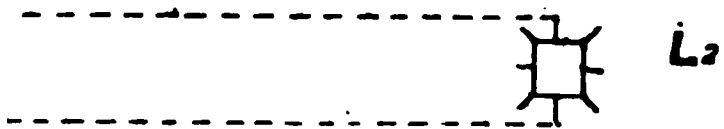
The dynamo itself should be bolted down to a block of masonry, if possible ; if not, it should be fixed on a rigid wooden framework, and in a room by itself, or railed off from other machinery and inquisitive onlookers, where it can be free from dust and damp and from metallic particles. It must be kept absolutely clean and free from oil and the dust caused by the wearing away of the brushes and the commutator.

In order to take up the slackness of the belt the dynamo is often mounted on rails as shown in fig. 283, at R, so that by adjusting the screws, *v v*, the belt can be either tightened or slackened. B is the masonry foundation, *b b* the holding-down bolts, D the brush holder, and E the brushes. In fig. 284, the side view, *c* is the commutator, and P P the two bearings. The pulley is shown in its place.

It has already been explained that in the compound shunt-wound dynamo the coils of the field magnets are wound partly with thick wire through which the whole current passes, and partly with fine wire through which a portion only is shunted from the terminals of the machine. Now this machine, if the speed is regular, will maintain a constant E.M.F. in volts, irrespective of the number of ampères of current which may be required from it by any variation in the outside circuit due to one or more lamps being turned on or off.

In order, however, to maintain a constant electromotive force, upon which the durability of the lamps depends, irrespective of any slight variations in speed, it is usual to place a series of resistance coils, (*s*, fig. 285), in the shunt circuit between the terminals, *c c'* of the dynamo, and by modifying this resistance, increase or diminish the amount of current sent through the shunt coils and so counterbalance any irregularities in the speed and maintain a fixed E. M. F., or difference of potential, between the main terminals, P N, of the dynamo.

The engine and dynamo having been fitted up, we must next consider the outside circuit and how to connect it with the dynamo in such a way that the arc or the incandescent lamps may be lit up at will either together or separately.



The conducting wires employed are of copper, insulated for interior work, but bare and supported by porcelain insulators on telegraph poles when used for outside work. The size of the wire depends on the strength of the current in ampères, and varies throughout the system according to the number of lamps in use, just as the diameter of a gas-pipe is varied according to the number of burners. The diameter of the wire is calculated on the basis of two ampères for each square millimetre of section of the wire.

Referring now to fig. 285, which is a sketch plan showing the general arrangement of a plant for lighting by arc and incandescent lamps, the two terminals, P N, of the dynamo are connected, the one to the main switchboard, B, the other to the fusible cut-out, E, to which all the return wires of the different circuits are brought and which, together with the switchboard and resistance coils, S, should be placed on the wall of the dynamo room in a convenient spot. The fusible cut-out, E, as well as all the other cut-outs in the various circuits, consists of a short length of lead wire fixed between two terminals which fuses if the current exceeds a predetermined limit, and so saves the whole circuit and the lamps from destruction. One of these cut-outs is placed at each principal junction in the incandescent system, the diameter of the lead wire being varied according to the amount of current it is designed to carry.

The series of resistance coils, S, for the shunt wires is shown in position, and their use has already been explained.

The pole, P, is connected to the positive bar, K, of the switchboard, and then branches off to the various circuits. For the incandescent circuit it is led first through a fusible safety cut-out, D D, and then to switch, I, by means of which it can be turned on or off, thus lighting or extinguishing the whole of the lamps at will. To each group of lamps, or to each lamp, if necessary, a smaller switch is connected, so that they are under absolute control. These switches, as well as the smaller fusible plugs and the way the lamps are connected, are clearly shown in the diagram.

The circuits of the arc lamps are somewhat more complicated. Each of these circuits—which may consist of two arc lamps,

working in series as at L_2 , with an E.M.F. of 120 volts, or of one arc in derivation, as L_1 , with an E.M.F. of 70 volts—traverses a regulating resistance coil, R , as well as a fusible cut-out, $D D$, and a switch, C , for interrupting or completing the circuit.

When the switch handle is in the position, $x y$, the circuit is closed and the lamp will light up. When the handle is in the position, $z w$, the lamp will remain alight, but the current will also pass through the ampèremeter, A , the needle of which will then indicate the strength of the current in ampères. In the position $v w$, the circuit will be interrupted and the lamps put out.

On each of the arc lamps will be found a label stating the number of ampères at which it should be worked. This exact number must be obtained by placing the handle in the position $z v$, and then varying the resistance by means of the sliding knob, H , until the needle of the ampèremeter indicates the number desired. This adjustment once made, the handle can be put in the position $x y$, and the lamp will continue to burn. It is advisable, however, to renew the test from time to time in case of any variation.

The first trial run of the installation must be conducted most carefully, and the dynamo should be allowed to run unloaded for a few hours. For this purpose the brushes are lifted from the commutator, and, after seeing that the machine is well oiled, a trial run should be made at the speed stated on the dynamo. During this trial the belt can be adjusted, the engine governor set to the proper speed, and various odds and ends seen to. Before lighting up, the following observations should be made:—

1. That the brushes are firmly fixed and properly adjusted so that they may touch the commutator on opposite points of the same diameter, and that their holders are not in the way of the revolving armature.

2. That there is no connection between any part carrying the current and the framework of the dynamo.

3. That all the principal switches are open, so as not to allow any current to pass.

4. That all the bolts and screws are tightened up.

5. That the belt is well stretched and smooth, as any uneven

ness in its surface will cause the lights to flicker and shorten the life of the lamps.

6. That the oil cups are full of clean oil. The best lubricant is a mineral oil of a density of .905.

Now raise the brushes and start the engine slowly ; then, after a few moments, lower the brushes until they touch the commutator. If no part commences to get hot and if the voltmeter, *v*, indicates the proper number of volts decided upon for the installation, a portion of the incandescent system can be turned on and then increased at intervals of a few minutes until all the lamps are in circuit ; and then, if all goes well, the arc lamp circuits can be added one at a time.

At each increase of the load in the dynamo it may be necessary to adjust the brushes by slightly turning round the brush-holder until there are no sparks.

If, when the dynamo is at work, the proper number of volts cannot be obtained even by altering the resistance, *s*, it is probable that the speed is too low, and must accordingly be increased until the proper number of volts, as indicated by the voltmeter, *v*, is obtained. Great care must, however, be taken that this number be not exceeded by more than 5 volts, as otherwise the incandescent lamps will be rapidly destroyed.

In order to stop the machine the switches must first of all be turned off and the engine then stopped, but before the armature has quite ceased to revolve the brushes should be lifted.

Great care should be taken not to bring any piece of iron near the machine when in motion. It is best even to use oil tins made of copper, as all iron tools are strongly attracted.

The contact surfaces of the switches, brushes, and commutators must always be kept quite clean.

No strangers or idlers should be allowed to tamper with the machine, or enter the dynamo room, or interfere with the conducting wires, nor should any examination of a circuit be made until the current has been cut off from that portion of it.

There are many minor but important details which require careful attention during the erection and maintenance of an electric light installation, but enough has already been said to give, I believe, a general idea of the whole and the most striking

features in connection with the dynamo and the circuit of conducting wires.

THE ARC LAMP.—The area of ground to be illuminated and the nature of the work to be carried on must be considered in choosing the candle-power of the lamps. In exceptional cases for large areas, where the lamp can be suspended at a height of say 100 ft. from the ground, an arc lamp requiring a current of

FIG. 286.—ARC LAMP.

50 ampères and equal to a light of 19,000 candles would be chosen.

Generally speaking, however, a lamp giving 4500 to 5000 candle-power, requiring a current of 24 ampères, and hung at a height of 50 ft., would be found ample for illuminating an excavation equal in area to a circle of 8000 square yards.

For still smaller works out of doors, or in large workshops, a lamp of 1500 candle-power, requiring a current of 13 ampères,

hung at a height of 30 ft., would be found convenient, especially in places where it would be desirable to use several lamps of small power instead of one of great intensity.

The arc lamp, such as that illustrated in fig. 286, is more efficient than an incandescent lamp, as regards the amount of light obtained from a given quantity of electricity; but both have their special applications. For outdoor use it must be protected by means of glass from the inclemency of the weather; but it should be remembered that all shades, even of clear glass, greatly reduce the illuminating power.

In the arc lamp the maximum is so arranged that the two carbons are kept at a certain distance apart, and over this distance the voltaic arc is formed which gives the light, the resistance thus offered to the passage of the current being overcome by its electromotive force.

The carbons employed in the lamps are consumed unequally, the upper one, which is connected to the positive pole of the dynamo, wearing away with twice the rapidity of the lower one. For this reason it is usual to make it of double the thickness of the other, so as to equalise the consumption. It will be noticed when in work, that a crater is formed in the extremity of the upper carbon while the lower one is always pointed.

The lamps are hung in such a manner that they can be easily lowered for cleaning and the renewal of the carbons. Great care must be taken in fixing the new carbons to put them exactly in line, point to point. It is hardly, perhaps, necessary to add that these lamps are not lit by means of a match, though I once found a boxful of burnt match ends at the foot of an electric light pole in a Welsh quarry, the explanation of which was that owing to a stoppage of the dynamo the lamp had gone out, and had been lowered by the night foreman, who ingeniously endeavoured to light it up again by the only means in his power.

Incandescent Lamps.—The pear-shaped glass globes within which is seen a thin horseshoe-shaped carbon filament, as in fig. 287, are now so well

FIG. 287.—INCANDESCENT LAMP.

known as to require but little description. They are attached to small, round wooden supports, on which are the terminals under which the ends of the conducting wires are screwed. These supports also serve to hold a tin shade, which reflects the light downwards. For household purposes they can be arranged in a great variety of ornamental and artistic ways with which, however, we have not at present to deal.

The life of an incandescent lamp depends entirely upon the regularity of the current. Its maximum may be 2000 hours, but variations in the speed, stopping, or bad joints in the driving belts will cause rapid destruction of the thin filament. Perhaps for

General View.

Section, Side.

Section, End.

FIG. 288.—HAND DYNAMO FOR ELECTRIC BLASTING.

workshop purposes the average life of the 16 candle-power lamp generally employed, may be taken at from 800 to 1000 hours. Hence the necessity which has all along been insisted upon, of an absolute regularity of speed, which, indeed, can only be obtained by having a motor, whether steam engine or turbine, devoted solely to the driving of the dynamo.

Electric lighting is now being largely introduced for the purpose of lighting up the main roads underground, both in collieries and mines. In economy it will compare very favourably with any other illuminating power, while, if water-power is available for driving the dynamo, it is cheaper than any other form, and gives a far better light with no danger of explosion.

ELECTRIC BLASTING.—The simultaneous discharge of a large number of holes is far more effective for the breaking down of rock, whether in tunnelling or quarrying, than is the result from the same number of holes fired separately. The best and safest way of attaining this is by the use of electricity, and the machine usually employed for generating the electric current is a portable arrangement of a small hand dynamo, such as that shown in fig. 288, which may be wound in such a manner as to give high or low tension currents.

These machines can be made to fire up to a hundred holes at a time; but the usual type is for about 12 to 15 holes.

The armature, B, is caused to revolve between the poles of the magnet, A, by means of the rack and pinion, B, during the down stroke only of the handle. As soon as the lower end of the rack comes in touch with the contact breaker, E, the current is directed to the outside circuit of fuses and the explosion takes place. If by chance there is a miss-fire the holes can be examined at once, after disconnecting the machine, as it is impossible for a fuse to hang fire as with gunpowder. I have worked with these machines on a large scale, and after personally superintending the operation for a few days, during which time I trained a man to make up the fuses, connect the wires, make the joints, and so on, I left the work solely in his charge, and although the number of holes often exceeded fifty in one blast, there was never any irregularity or trouble.



FIG. 289.
ELECTRIC.
FUSE.

The fuse used with a low tension machine is shown in fig. 289, in which A is a shell of copper, having a slightly raised rim for the purpose of holding the sulphur stopping, F, in its place; the exterior wires, F, terminate in two pin points, D, forming a bridge, across which a connection is made by means of a fine platinum wire. On the current passing, this wire becomes red-hot and fires the explosive fulminate contained in the head of the shell, which has been inserted in the central hole of a dynamite cartridge, as usual with ordinary caps.

The wires attached to the caps may be cut of any length to suit the depth of the holes and are generally left, the one slightly

longer than the other, in order that the two joints may not be close to each other. The holes and fuses are joined in series, as shown in fig. 290, and great care should be taken that the joints between the wires should be properly made. For this purpose the insulating cover is removed for an inch or two, and the bare wire brightened with emery cloth. The ends thus cleaned can then be twisted together, thus connecting the line of holes. The starting wire of the first hole, and the terminal wire of the last one are then joined on to each of the connecting insulated wires, which in turn are fastened to the binding screws of the battery. All being now ready and the miners in safety, the handle is raised

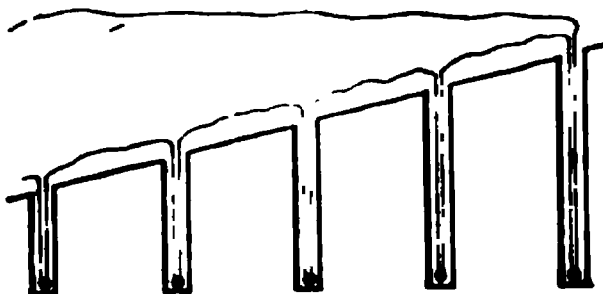


FIG. 290.—ELECTRIC BLASTING, ARRANGEMENT OF CONNECTING WIRES.

to its full height and pressed firmly down. When it touches the spring at the bottom the shots will be fired.

The points to be attended to are to make clean and perfect joints, and to so twist the wire at the joints that these do not come into contact with the rock, which might lead to the short circuiting of some of the holes. The firing cartridge may be placed at the bottom of the hole, as a better explosive effect is thus obtained; but care must be taken, when tamping, that the insulating covering is not removed from the wires.

There are many types of blasting machines on the market, but those embodying the principle of a hand dynamo are preferable to the high tension friction machines which often refuse to work, especially in damp weather.

CHAPTER XXIX.

AERIAL WIRE ROPEWAYS AND WIRE ROPES.

Systems of Ropeways—The Otto Ropeway—Standards—Ropes—Carriers—Trucks—Friction Grip—Working—Angle and Power Stations—The Ganucha Line — Description and Cost of Working—Wire Ropes for Transmission of Power—Wire Ropes—Preservative Coating—Strength of Round and Flat Ropes—Splicing Ropes—Wire Rope Attachments.

AERIAL WIRE ROPEWAYS.—The question of the transport of the ore, either from the mine to the mill or of the dressed mineral from the mill to a port or railway station, is one of vital importance, and is in many cases the sole reason for leaving mining properties undeveloped, or for the abandonment of undertakings which, if a ready solution of this difficulty could have been obtained, would now be in successful work.

The great cost of constructing ordinary railways, and even tramways, due in some cases to the value of the ground, and in others to its physical features forbidding their adoption, has led to the successful introduction of a new method of transport.

These difficulties vanish when the aerial wire ropeway is employed; for by its long spans, in some cases of 1500 ft., it passes over all obstacles, while it hardly affects the value of the land, of which none need be purchased for the permanent way. All that is required is the lease of a strip of ground, 10 ft. wide, which is occupied only at the points of support, and can otherwise remain in cultivation as usual.

There are two systems of aerial ropeways: the one consists of an endless running rope, fulfilling the dual function of carrying and hauling rope for the buckets, and connected with the names of Hodgson and Hallidie. This class is in use in America and

northern Spain; and, in spite of its simplicity and cheapness, is surrounded with many difficulties in the actual working, and is being superseded by the German system, which consists of the use of two ropes—a heavy fixed carrying rope and a light traveling hauling rope—to which the buckets are fixed by means of special gripping devices.

This last system is generally known as the Otto, or the Bleichert, both of which gentlemen have been instrumental in bringing it to perfection. I have also had some personal experience of its erection and working in connection with a lignite briquette

FIG. 291. THE OTTO AERIAL ROPEWAY.

factory, near Aix-la-Chapelle; and in the following description of it I make use of notes then taken, and of information supplied to me by Messrs. Commans and Co., 52, Gracechurch Street, E.C., who are the English representatives of the makers.

The carrying capacity of the aerial ropeway has increased with the demands made upon it. Ten years ago the maximum loads were from 4 to 5 cwts.; now, however, they vary between 10 and 20 cwts., so that the carrying capacity is now from 600 to 800 tons per day of 10 hours; while there are ropeways in work of from 8 to 10 miles long.

The standards which support the ropes are usually placed a

from 100 to 200 ft. apart, according to the configuration of the ground, of which a survey and section should be carefully made. The spans may, however, under special circumstances, be as great as 1500 feet, say, when crossing narrow valleys or rivers. The supports are made of wood or iron as shown in figs. 292 and 293, and are usually stayed with wire rope guides. When of wood the legs may be ordinary round poles, with the top cross pieces of



well-seasoned oak. If built of iron the uprights are usually constructed of channel or I-beams, stiffened with angle iron, and the crosspieces are made of channel iron. For heavy loads and great spans the standards are constructed with four legs.

The arrangement for carrying the ropes is shown in the illustration. The fixed rope rests simply in an iron shoe so constructed as not to offer any resistance to the passage of the wheels of the carriers.

The buckets support the hauling rope at frequent intervals ;

but when these are long the rope runs over the rollers fixed on arms projecting from the stavelards.

The carrying or fixed ropes are specially designed of stout

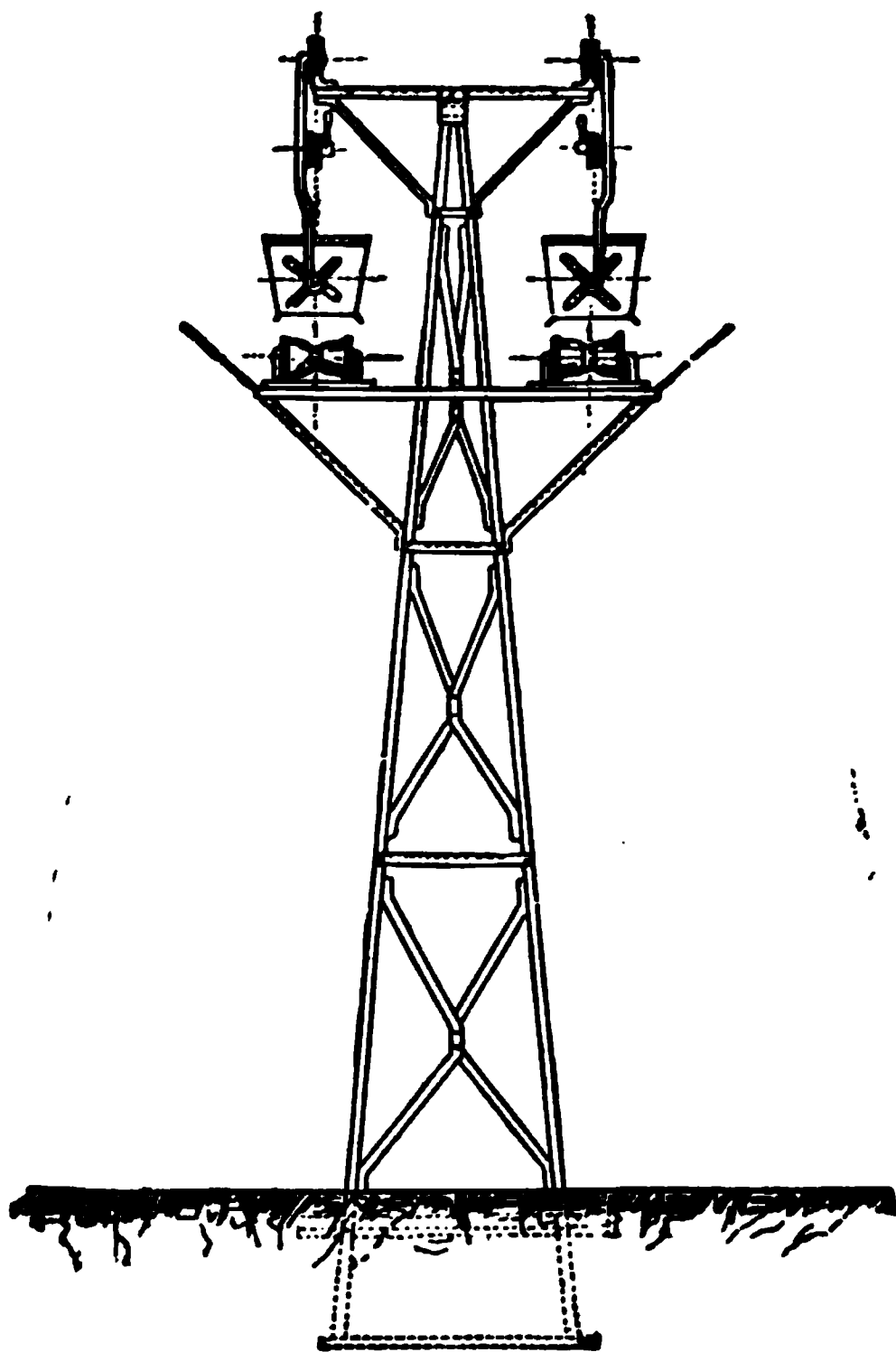


FIG. 293.—OTTO AERIAL ROPEWAY, IRON STANDARD.

steel wire, 4 to 7 millimetres or $\frac{5}{32}$ to $\frac{9}{32}$ in. in diameter, which has a breaking strain of from 38 to 76 tons per square inch.

The hauling ropes, on the other hand, in order to be as flexible as possible, are made with a hempen core and of fine steel wire, which has a breaking strain of 120 to 180 kilogrammes, or from 76 to 114 tons per square inch.

The carriers are made in a great variety of designs according to the nature of the material to be transported.

For the conveyance of mineral sheet iron buckets are used,

FIG. 294.—CARRYING BUCKET FOR AERIAL ROPEWAY.

such as that shown in fig. 294, which are provided with special tipping arrangements.

The carriers are suspended from trucks or runners, such as that

illustrated in fig. 295, which has been in use for over six years, and entirely overcome the faults of the earlier trucks, in which the spindles of the grooved wheels were supported on one side only. By supporting them on both ends the wheels are not liable to skew, and the carriers are bound to hang always vertically.

The frame of the truck consists of two steel plates connected in the middle by a cast-iron distance piece, through which the spindle of the hanger passes, and at each end by a phosphor

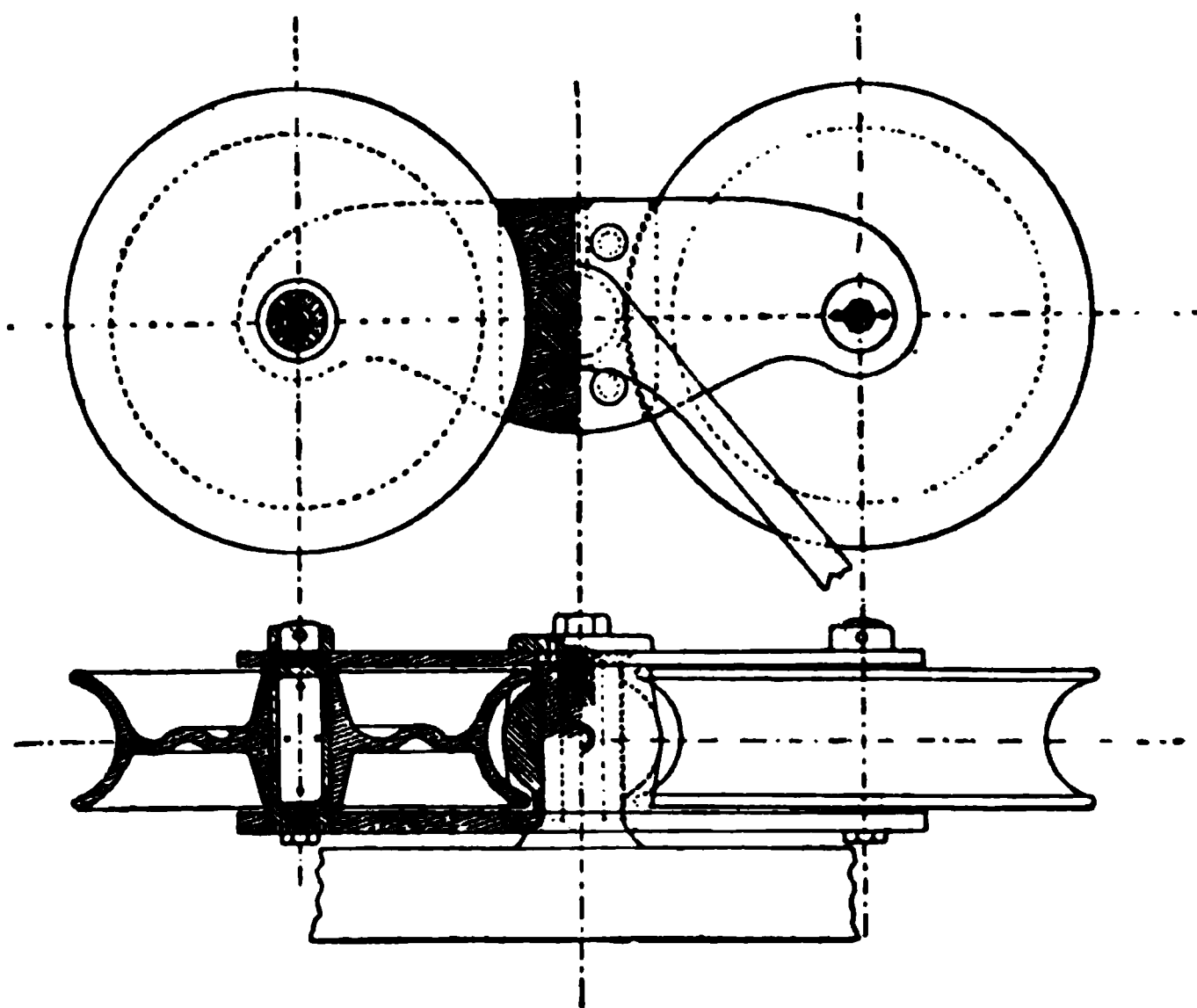


FIG. 295.—PLAN AND SECTION OF TRUCK OR RUNNER OF AERIAL ROPEWAY.

bronze distance piece, which forms the spindle for one of the grooved wheels. Each of these spindles is hollowed out to contain a lubricant, which is introduced by removing the thumb-screw shown in the end.

The lubricant passes through small holes to the surface of the spindle, and effects by this method such a perfect system of automatic lubrication that the spindles and rollers are preserved from almost every sign of wear even after many years' use.

Another equally important detail is to ensure regular and uninterrupted working in the form of coupling or grip for attaching the carrier to the hauling rope. This must not only be simple in design, but absolutely reliable in its action, and should reduce the wear on the hauling rope to a minimum. The friction grip and the lock grip are the two forms usually employed. With the former the carriers can be attached to the hauling rope at any point; with the latter, small collars or carrier knots have to be fixed at intervals along the hauling rope corresponding to the distance apart at which it is intended to attach the carriers.

FIG. 296.—DISC FRICTION-GRIP OF AERIAL ROPEWAY.

The form of friction grip in most general use is that shown in fig. 296, and consists of two smooth-faced discs—one rigidly attached to the cross bar of the hanger, and the other mounted loosely on a spindle and free to revolve, acting, when necessary, as a carrying roller for the hauling rope. The spindle has a square thread on its outer end, and carries a lever, the boss of which forms the nut. When the lever is down the discs do not grip the rope, but are kept apart by a spring. As it is raised the discs approach each other, and when up the hauling rope is tightly gripped. The lever is prevented from falling back by a small

spring trigger. As the carrier bucket approaches a station, the lever and trigger both encounter a stop which throws them over, separating the discs and automatically releasing the hauling rope. The bucket is then free to be switched off the carrying rope to a siding. The discs can easily be adjusted, allowing for the size and wear of the rope. This form of grip is employed for gradients up to 1 in 6, and for loads of 450 kilogrammes (9 cwt.) net weight.

For steeper gradients, up to 1 in 3, where a friction device is still practicable, a more powerful grip with corrugated jaws is used instead of the smooth-surface discs. One of the jaws is rigid, while the other is moved in and out by means of a lever and cam, so as to grip the hauling rope. Both forms of friction

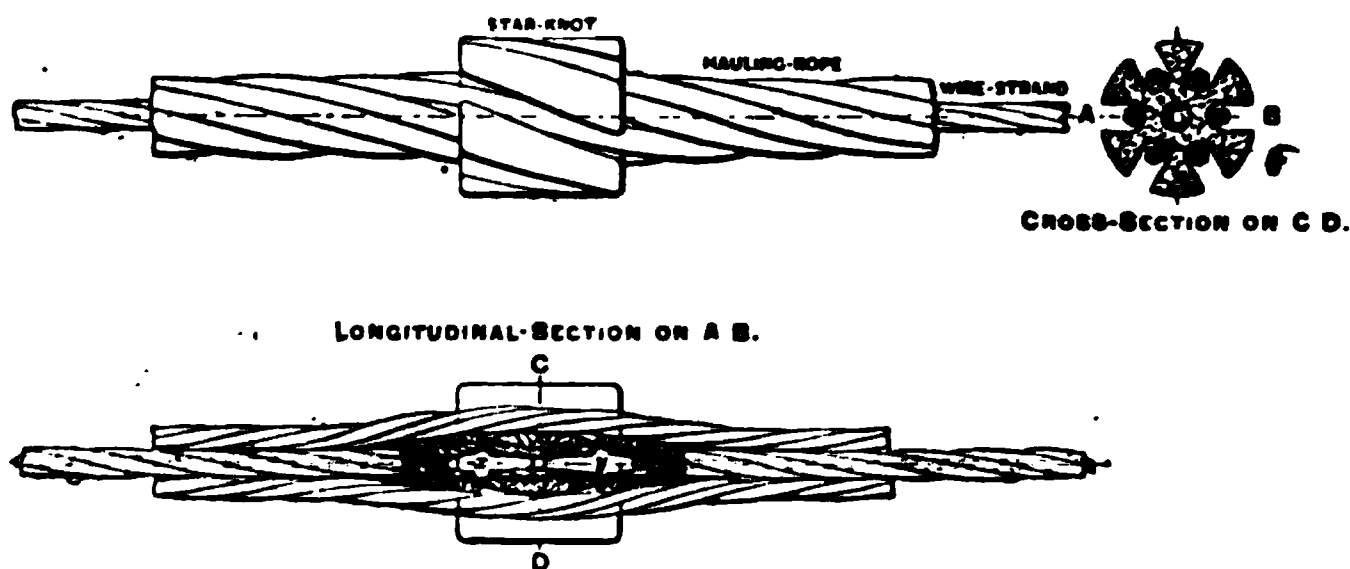


FIG. 297.—STAR-KNOT ON HAULING ROPE OF AERIAL ROPEWAY.

grip have given satisfaction. Since the buckets can be attached to the hauling rope at any point, the tendency to a uniform wear throughout the length of the rope is promoted, and this is a distinct gain. Another advantage in using friction grips is, that the carrying capacity of the line can be easily altered simply by adding more carriers at shorter intervals, without varying the travelling velocity of hauling rope, the speed of which is about $3\frac{1}{3}$ miles per hour.

For lines having gradients under 1 in 6 the disc grip is the best existing form, as it subjects the hauling rope to the least wear. In the case of the Fernie ropeway, erected in Giesen in 1879, the original hauling rope was still in regular work in 1891.

For gradients steeper than 1 in 3 a lock grip of some kind is

absolutely necessary. The number of buckets and the corresponding capacity of the line for a given speed are then limited by the spacing of the knots on the hauling rope. The design of the knot is of almost as great importance as that of the grip itself; and the one which experience teaches is the best is what is known as the Star knot, illustrated in fig. 297. It consists of a cylinder whose diameter is somewhat greater than that of the hauling rope, and whose surface is provided with spiral grooves

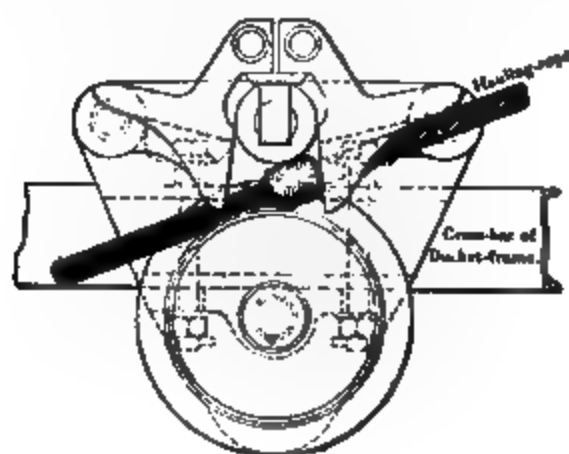


FIG. 298.—PAWL GRIP OF AERIAL ROPEWAY.

into which the strands of the hauling rope are inserted. When the knot is in its place, its ribs project sufficiently beyond the hauling rope to furnish a hold for the pawls of the grip. In order to secure the knot in its position with absolute certainty a steel wire strand about two yards long is passed through it and fixed by the two wedges, *x* and *y*. When the knot is to be attached to the hauling-rope, the latter is first untwisted, and two yards of the hemp core are removed. The knot and the steel wire strand, which takes the place of the hemp core, are then set

into the rope, and when this has been twisted tight its hold upon the knot and strand is sufficient to resist any shock to which they may be subjected.

The grip best adapted for use when the steepness of the gradients requires knots on the hauling rope is the pawl grip shown in fig. 298, which is extremely simple, never fails, and needs no repairs.

It consists of two symmetrically-disposed pawls, each free to move on a vertical plane, and having forked ends which drop down on either side of the knot, the drop being checked by a stop. The rope is supported on a roller just below the pawls. To throw the pawls in and out of action the toe of each pawl carries a pin, which engages with a guide rail at the station.

The process of coupling a bucket fitted with one of these grips is as follows: The workman moves the bucket by hand along the switch rail to the carrying rope: on approaching this the pawl pins come in contact with the guide rail, raising the pawls so as to allow the hauling rope to be guided, and rest on the roller, which is immediately below them, and forms part of the grip.

As soon as the bucket rests on the carrying rope, the pins are released from the guide rail, and the pawls fall down in position over the hauling rope. As a knot approaches it lifts the first pawl, which, however, falls back into its original position; but the second one resists, and the bucket is automatically taken in tow. To avoid a violent impact of the knot upon the coupling, the shunter gets a bell-signal when a knot is approaching, and he pushes off the bucket at about the same velocity as the rope is travelling. The uncoupling is similarly effected. As the bucket nears the station, the pawl pins come in contact with a guide rail, lifting the pawls out of gear, and releasing the hauling rope; the bucket, by virtue of its momentum, then moves off the carrying rope, and up a tongued rail which switches it into a siding. This is probably the only lock-coupling that is constructed so as to be thrown in and out of gear automatically, and has been successfully and safely used in transporting loads of more than one ton on mountain lines up gradients of 1 in 1.

The carrying ropes are firmly anchored at the terminal stations

to masses of masonry, and are kept taut by means of tenon

FIG. 299.—OTTO AERIAL ROPEWAY. PLAN AND SECTION OF ANGLE AND POWER STATION.

weights fixed at the angle stations, as shown in fig. 299, which represents a power and angle station on the Garucha line in

Northern Spain. These angle stations are necessary in those cases where the ropeway cannot be constructed in a straight line from end to end. When the buckets arrive at an angle station they are automatically disengaged from the hauling rope, switched on to the shunt rails, and run round by hand to the carrying rope on the next section of the line, where they are again attached to

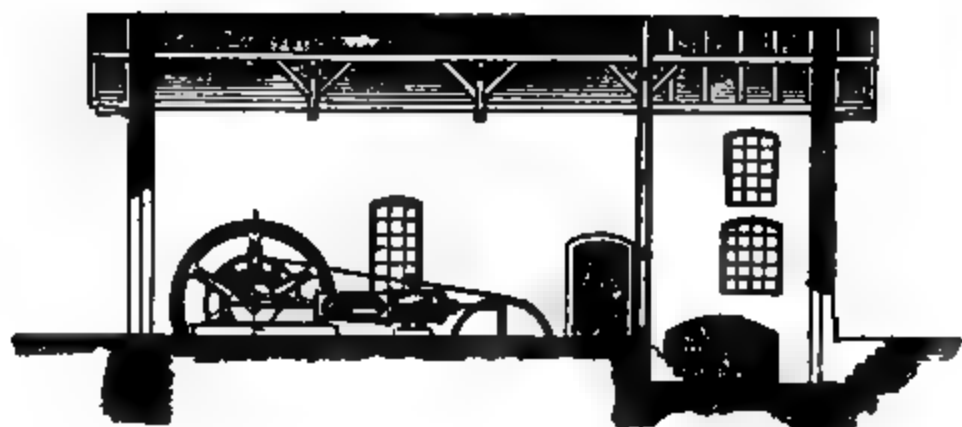


FIG. 300.—OTTO AERIAL ROPEWAY. SECTIONS OF ANGLE AND POWER STATION.

the hauling rope and sent off in the new direction. The arrangement of the shunt rails and tenon weights of an angle station, together with the hauling engine, is shown in plan and section in figs. 299 and 300. The power is transmitted by belt and gearing to two large grooved pulleys, lined with leather, about 7 ft. 3 in. in diameter, around which the hauling rope is several times

coiled. This rope is kept taut by means of tension weights and pulleys similar to those of the carrying rope.

The Garucha line just referred to is one of the most important of the Otto ropeways yet constructed. It is used for the transport of iron ore from the mines at Serena de Bedar to the Mediterranean coast at Garucha, a distance of $9\frac{1}{2}$ miles. The line is divided into four sections, the first two of which are 1.40 and 3.29 miles long respectively, and are driven by means of a 30 horse-power engine; and the second two sections are 3.29 and 2.8 miles long, worked by a 70 horse-power engine.

After leaving the loading station at Serena, which is 905 ft. above the sea level, the line crosses a number of deep valleys, one of which is over half a mile wide and 328 ft. deep, and traverses mountain ridges, the highest of which is 1174 ft. above the sea level, to the village of Pendar de Bedar, where, at an elevation of 951 ft., the first power station is located.

From here the line deflects to the right, and again passes over several valleys and ridges, with a gradual descent to an angle station 370 ft. above the sea level. It then bears to the left, extending over a more or less hilly country to the second power station near Puerto del Coronel, of which a plan and sections are given in figs. 299 and 300.

From this point the line turns to the right, and descends at an easy gradient to the unloading station on the coast near the town of Garucha.

The greatest span of the line near the Villa Reforma is 918 ft. wide, and here the rope sags 65 ft. and carries 6 loaded and 6 empty buckets at a time.

The other long spans of the line range from 328 ft. to 750 ft., but the average distance between the supports is only about 130 ft. The steepest gradient, taking into account the sag of the rope, is 1 in $2\frac{1}{2}$, and the tallest standard is 118 ft. high. The guaranteed capacity of the line is 400 tons per day of 10 hours. With a travelling rate of 300 ft. per minute, or about 3 miles an hour, and with two buckets of 7 cwt. capacity arriving per minute, or say 1200 buckets per day of 10 hours, the actual quantity carried by this line is 420 tons, making its capacity 4095 ton-miles. Owing to the increased demand for Bedar ore, the line has been

worked since the commencement of 1890 in two shifts of 8 hours, and no less than 900 tons per day have been transported to the coast.

The carrying ropes for the loaded and unloaded side respectively are $1\frac{5}{8}$ and 1 in. diameter, and the size of the hauling rope is about $\frac{3}{4}$ in. The latter is fitted with the star knots already referred to, and the pawl grips are used throughout.

At the loading station, bins of 800 tons aggregate capacity are erected, from which the ore is spouted into the buckets. The engine and boiler houses are solidly built, and are large enough to be used as repairing shops.

The unloading station at the coast is 150 ft. long \times 50 ft. wide and 32 ft. above the ground level. Its storage capacity is from 18,000 to 20,000 tons, so that from 4 to 6 vessels can be loaded at a time. At the various stations sidings are arranged for stocking empty carriers from various sections of the line. Electric signals are used, and the stations are connected by telephone. The line was surveyed, constructed, and ready for work within ten months, and its total cost was £26,000. The constructor of the line (Mr. J. Pohlig, of Cologne) contracted to work and keep the line in repair for a number of years at the rate of 1s. $2\frac{1}{2}$ d. (28·8 cents.) per ton carried, this price to cover all the costs for labour, maintenance, and repairs. The use of aerial ropeways is now greatly extending, and many lines are being erected on the South African Goldfields for the conveyance of quartz.

WIRE ROPE TRANSMISSION OF POWER.—It frequently happens in laying out the design for a mill that the source of water-power is situated at some little distance from the site of the mill; not so far as to necessitate the use of electricity as a means of transmission of power, and yet at such a distance as to create some little difficulty as to its application.

If this distance is under a mile the most economical and simple method of overcoming the difficulty is by the use of wire rope running in V-grooved pulleys. The pulleys are made of cast iron or steel of as great a diameter as possible, in order to avoid the loss caused by the bending of the rope over a small pulley, both in friction and in wear and tear of the rope. Wheels over

8 ft. in diameter are made in sections, and the groove is always lined with leather or other soft material. The rope travels at a speed of about 80 ft. per second.

The distance to be traversed is divided into section according to the configuration of the ground.

At each section a pair of wheels keyed to one shaft is erected on a suitable foundation of wood or masonry.

The one wheel receives the power from the preceding station by means of the wire rope, which takes the place of an ordinary leather belt, while the other transmits it by another rope to the succeeding station, and so on until the mill is reached.

The approximate cost of such a system for the pulleys, bearings, wire ropes, etc., necessary for transmitting 50 horse-power a distance of 3000 ft. would be about £800, and for 100 horse-power, the same distance, about £1200. These figures do not include the cost of erection or of the prime motor engine or turbine.

The efficiency of such a system diminishes with the number of stations employed, and, according to Stahl, is as follows :—

Number of Intermediate Stations.	Efficiency of System.	Per cent. of Power Wasted.	Number of Intermediate Stations.	Efficiency of System.	Per cent. of Power Wasted.
0	0·962	3·8	3	0·908	9·2
1	0·944	5·6	4	0·890	11·0
2	0·925	7·5	5	0·873	12·7

The use of wire ropes for the transmission of power is, however, limited to short distances, and for these it compares favourably with the other methods. Practically it may be said that electric transmission will, in the future, supersede all other means as being the most economical and efficient ; and of this I have given full details in Chapter XXVII.

Compressed air can and is, indeed, used for the same purpose, and has the great advantage of being useful for ventilation, after it has been deprived of its power. In metalliferous mines this is perhaps of not so great importance, but in collieries where every additional cubic foot of air is of value, the exhaust from pumps

and hauling engines driven by compressed air is especially welcome, and is delightfully fresh and cool as compared with the hot, dust-laden air which has circulated through miles of roadways.

From this point of view compressed air as a means of transmission of power appears to great advantage, but, on the other hand, when all the losses due to compression, friction in, and leakage of pipes, and reconversion into power are taken into consideration, it does not compare favourably with electricity. These points may be studied in Chapters VII. and VIII., which treat of compressed air as applied to Rock Drilling.

WIRE ROPES.—Wire ropes are so extensively used in mining for transport purposes, hoisting, hauling, the transmission of power, and other similar purposes, that a few observations will not be out of place as to their strength, durability, and maintenance.

They are usually made of six strands laid about a centre core of hemp or wire, the former being more pliable, and wearing better over small drums and pulleys, although it conduces to the longevity of the rope that these should be of as great a diameter as possible.

The strands are each composed of nineteen wires, where great flexibility is required, as for hoisting ropes, and of seven or twelve wires for stiffer ropes, as those used for guys, ferries, rigging, and transmission purposes.

Wire rope is as pliable as hemp rope of the same strength, but care should be taken not to coil it for storage, or uncoil it in the same manner as is usual with hemp rope.

In order to prevent it from kinking, it should either be wound on a reel or rolled upon the ground like a wheel.

Galvanised wire rope should not be used as a running rope, as the coating of zinc would wear off in a day's work, and the exposed wires soon begin to rust.

To preserve wire ropes from the action of the weather they should be thoroughly coated with a mixture of raw linseed oil and vegetable tar. For wet places and underground work the rope should be saturated in a hot mixture, made by boiling a barrel of mineral or vegetable tar, and adding thereto a bushel of fresh slaked lime.

The wear of the rope may be greatly reduced, and its life lengthened, by attention being paid to the surfaces of the pulleys, sheaves, drums, etc., over which it is run. The grooves should be lined with well-seasoned blocks of hard wood set on end, rubber, leather, or some soft metal, thus securing not only a greater adhesion, but also increasing the life of the rope.

The safe working load may be fixed at from one-fifth to one-seventh of the ultimate strength, according to the speed and vibration. It is better to increase the load than the speed, as this latter increases the wear.

The following tables give the sizes, weight per fathom, and the breaking and loading strain for round and flat ropes :—

ROUND ROPES.

SIZES.		Weight per Fathom.	PLOUGH STEEL.		PATENT STEEL.		IRON.	
Circum- ference.	Diameter.		Breaking Strain.	Working Load.	Breaking Strain.	Working Load.	Breaking Strain.	Working Load.
inches.	inches.	lb.	tons.	cwt.	tons.	cwt.	tons.	cwt.
1	$\frac{5}{16}$	1	4	8	3	6	1	2
1 $\frac{1}{4}$	$\frac{7}{16}$	2	7	14	5	10	2	4
1 $\frac{1}{2}$	$\frac{15}{32}$	2 $\frac{1}{2}$	10	20	6	12	3	6
1 $\frac{3}{4}$	$\frac{9}{16}$	3	13	26	8	16	4	8
1 $\frac{7}{8}$	$\frac{13}{16}$	3 $\frac{1}{2}$	15	30	9	19	4 $\frac{1}{2}$	9
2	$\frac{5}{8}$	4	17	34	11	22	5	10
2 $\frac{1}{4}$	$\frac{23}{32}$	5	22	44	15	30	7	14
2 $\frac{1}{2}$	$\frac{3}{4}$	5 $\frac{1}{2}$	24	48	16	32	8	16
2 $\frac{3}{4}$	$\frac{25}{32}$	6	27	54	19	38	9	18
2 $\frac{7}{8}$	$\frac{11}{8}$	6 $\frac{1}{2}$	30	60	20	40	12	24
2 $\frac{3}{4}$	$\frac{27}{32}$	7	33	66	23	46	13	26
3	$\frac{11}{8}$	8 $\frac{1}{2}$	37	74	27	54	15	30
3 $\frac{1}{4}$	1 $\frac{1}{8}$	10	47	94	29	58	17	34
3 $\frac{1}{2}$	1 $\frac{1}{4}$	11	56	112	34	68	19	38
3 $\frac{3}{4}$	1 $\frac{3}{8}$	13	63	126	41	82	22	44
4	1 $\frac{1}{2}$	15	71	142	47	94	25	50
4 $\frac{1}{4}$	1 $\frac{5}{8}$	17	85	170	54	108	28	56
4 $\frac{1}{2}$	1 $\frac{3}{4}$	19	92	184	60	120	31	62
4 $\frac{3}{4}$	1 $\frac{7}{8}$	21	99	198	67	134	36	72
5	1 $\frac{1}{2}$	24	107	214	78	156	42	84
5 $\frac{1}{4}$	1 $\frac{9}{8}$	27	119	238	83	166	46	92
5 $\frac{1}{2}$	1 $\frac{5}{4}$	30	130	260	89	178	50	100
5 $\frac{3}{4}$	1 $\frac{3}{2}$	32 $\frac{1}{2}$	138	276	97	194	52	104
6	1 $\frac{1}{2}$	35	148	296	107	214	59	118

The above weights are for hemp cores in strand and centre of rope ; if wire cores weight will be about one-seventh more.

FLAT WIRE ROPES.

Breadth.	Weight per Fathom.	PLOUGH STEEL.		PATENT STEEL.		IRON.	
		Breaking Strain.	Working Load.	Breaking Strain.	Working Load.	Breaking Strain.	Working Load.
inches.	lb.	tons.	cwt.	tons.	cwt.	tons.	cwt.
$2\frac{1}{2} \times \frac{1}{2}$	12	47	94	32	64	16	32
$2\frac{3}{4} \times \frac{1}{2}$	14	54	108	38	76	18	36
$3 \times \frac{1}{2}$	16	74	148	50	100	23	46
$3\frac{1}{4} \times \frac{1}{2}$	18	81	162	56	112	25	50
$3\frac{1}{2} \times \frac{1}{2}$	20	93	186	61	122	30	60
$3\frac{3}{4} \times \frac{1}{2}$	23	111	222	72	144	32	64
$4 \times \frac{1}{2}$	25	120	240	83	166	36	72
$4\frac{1}{4} \times \frac{1}{2}$	29	126	252	90	180	44	88
$4\frac{1}{2} \times \frac{1}{2}$	31	140	280	102	204	53	106
$4\frac{3}{4} \times \frac{1}{2}$	34	148	296	106	212	61	122
$5 \times \frac{1}{2}$	37	160	320	110	220	69	138
$5\frac{1}{4} \times \frac{1}{2}$	38	163	326	119	238	70	140
6×1	40	168	336	120	240	75	150

The above weights are for hemp cores in strand and centre of rope ; if wire cores weight will be about one-seventh more.

Flat ropes are frequently preferred for hoisting purposes, as, owing to their being coiled one layer above the other on the winding drum, the motion of the engine is balanced ; the one drum being of small diameter when the heaviest weight of the rope is upon it, and the other of large diameter when the cage is at the top of the shaft, and but little rope paid out.

This compensation cannot be effected with round ropes unless conical drums are employed.

SPLICING ROPES.—The best form of rope for splicing is that made with six strands, as the strands are then the exact size for the core of rope, and are readily substituted for the core as it is being pulled out to allow the strands to take its place.

Five-strand ropes are also frequently spliced, and will hold more firmly than the six-strand rope, owing to the strands being a little larger than the core in the rope, so that when the splice is completed the outside strands press or grip more firmly upon the inserted strands, and thus prevent the possibility of the splice drawing ; but when these ropes are bent round small diameters in the course of working the inserted strands are apt to protrude.

In splicing wire rope the greatest care should be taken to leave no projecting ends or thick parts in the rope. Heave the two ends taut, with block and fall, until they overlap each other about 20 ft. Then open the strands of both ends of the rope for a distance of 10 ft. each; cut off closely the main heart or cores (see fig. 301), and then bring the open bunches of strands face

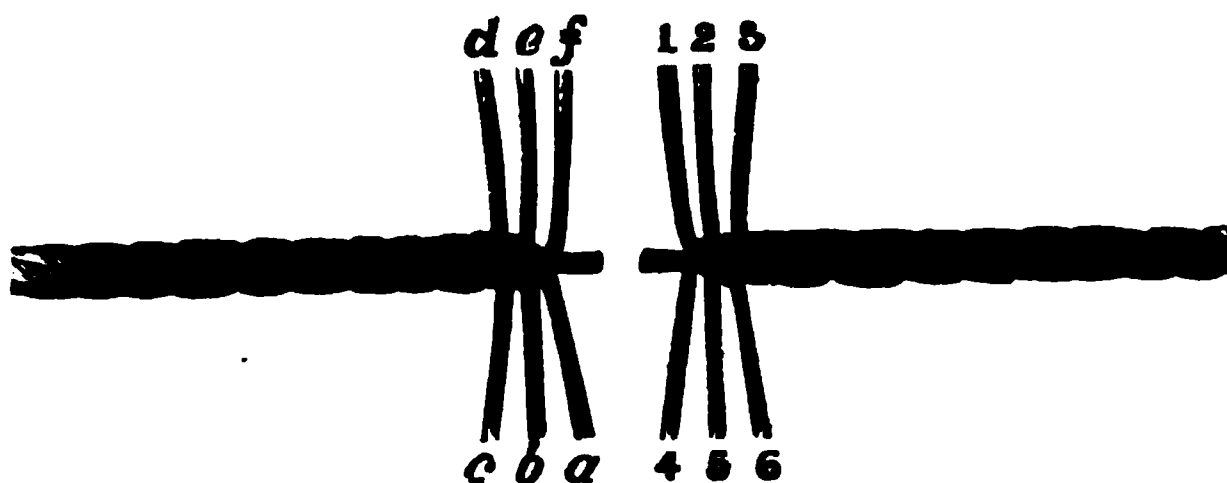


FIG. 301.—SPLICING WIRE ROPE.

to face, so that the opposite strands interlock regularly with each other.

Secondly. Unlay any strand, A, and follow up with the strand, 1, of the other end, laying it tightly into the open groove left upon unwinding, A, and making the twist of the strand agree exactly with the lay of the open groove, until all but about 6 in.



FIG. 302.—SPLICING WIRE ROPE.

of 1 are laid in, and A has become 20 ft. long. Next cut off A within 6 in. of the rope (see fig. 302), leaving two short ends, which should be tied temporarily.

Thirdly. Unlay a strand, 4, of the opposite end, and follow up with the strand, F, laying it into the open groove, as before, and treating it precisely as in the first case (see fig. 302). Next

pursue the same course with B and 2, stopping, however, within 4 ft. of the first set; next with E and 5; also with C, 3, and D, 4. We now have the strands laid into each other's places, with the respective ends passing each other at points 4 ft. apart, as shown in fig. 303.

Fourthly. These ends must now be secured and disposed of without increasing the diameter of the rope in the following manner: Insert marlinespike through the centre of rope, and cut out 6 in. of main core, and place the end of 1 under A into the place occupied by the core, and then cut out the core in the same way on the right, and place the end of A into the place of the core in like manner.

The ends of the strands should be straightened and lapped with fine hemp siezing before being put in. Then dispose of the remaining ends alternately in the same manner. After having done this the rope should be well closed, and any unevenness or irregularity can be taken out by pounding it with a wooden mallet.

In cases where ropes are heavily worked, when tucking in the ends, pass No. 1 over A, and B over No. 1. This mode of splicing ensures a very tight grip, and has been found to answer admirably.

The various kinds of wire rope attachments in ordinary use are shown in fig. 304.

A hardly requires any explanation; the end of the rope is simply bent around a gimbal ring, and then covered with clamps.

B is very neat in appearance, but cannot be effected except by skilled workmen used to splicing.

C, D, E. These attachments are made by, first of all, enlarging the end of the rope to a conical shape, best effected by turning back the wires

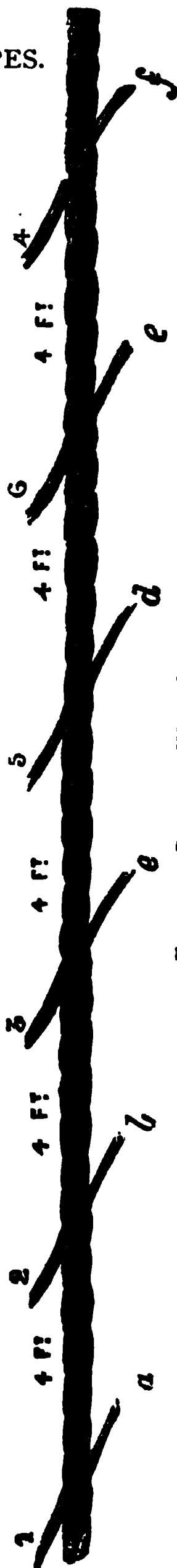
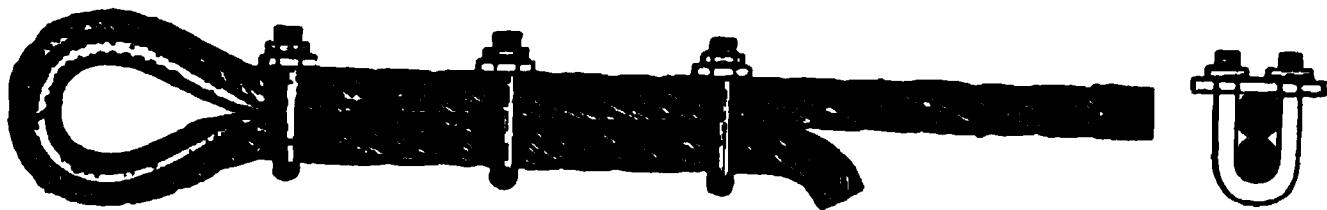
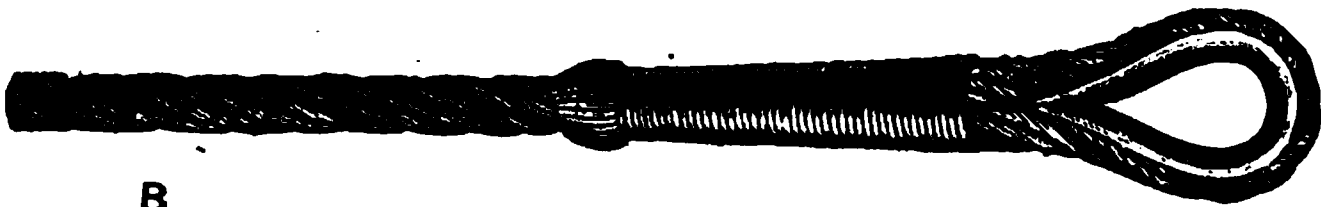


FIG. 303.—SPLICING WIRE ROPE.

layer by layer, and binding them down with copper wire. The first layers are longer than each succeeding layer, and thus the desired conical shape is obtained. The ring is made with long tapering ends fitting closely to the rope, and over these, in fig.



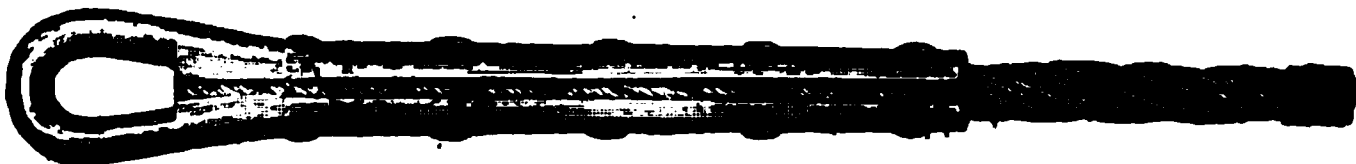
A Capel with Clamps.



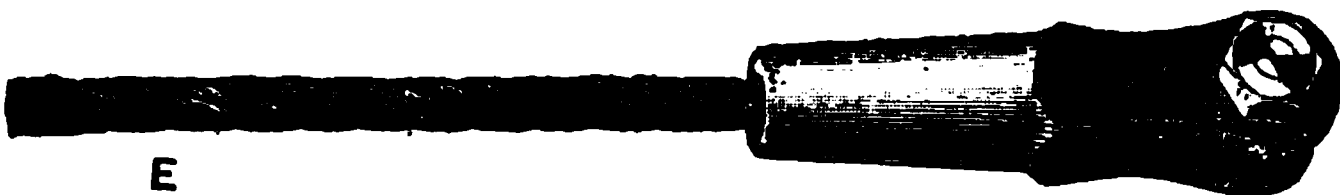
B Eye Spliced in.



C Capel Wire Conductors without Rivets.



D Capel with Rivets.



E Conical Socket without Rivets.

FIG. 304.—WIRE ROPE ATTACHMENTS.

304, three iron rings are driven while hot, and tighten in shrinking.

In fig. D rivets are used instead of the rings ; and in E the rope is run through the solid iron head until its cone-shaped head fits into the cone bored out of the solid head.

CHAPTER XXX.

TRANSPORT BY RAIL AND ROAD.

Useful Labouring Force of Man—Units of Work—Day's Work for a Man—Tramming Horse Traction—Loss by Friction over Road and Rail—Approximate Day's Work for a Trammer—Approximate Day's Work for a Horse—Inclines—Gauge—Rails—Sleepers—Portable Railway Plant—Laying the Line—Weight of Metal—Points and Crossings—Tram Waggon—Side Trip Waggon—Traction Engines—Hill Climbing Power—General Arrangements—Cost of Traction—Cost of Engines.

THE question of transport is one which is intimately connected with that of successful mining, and is, indeed, often the crucial point which decides the continuation of the work at a mine, or its abandonment.

I have already, in Chapters XXVII. to XXIX., described the appliances used for electric haulage and aerial tramways; and in this, the last chapter of my work, I purpose indicating briefly the arrangements connected with tramways as applied to mining, and also transport by means of road locomotives or traction engines.

TRAMWAYS.—The use of tram rails and waggon is now so universal in mining that we need not refer to the older methods of carrying the ore in baskets on the head, nor, indeed, to transport in panniers on mule or horseback, which hardly come under the head of machinery; and will therefore pass on to consider first the amount of work which can be done by tram-waggon propelled by manual and horse-power, and afterwards the appliances used for the purpose.

The useful effect or labouring force of a man working under varying conditions is clearly shown in the following table (from Morin), in which the unit of work is one pound avoirdupois, raised vertically one foot per minute.

The units of work are obtained by multiplying the height in feet by the weight in pounds ; thus the units of work in raising 200 lb., 50 ft. high $= 200 \times 50 = 10,000$. The units of work done in raising a weight up an inclined plane are equal to the work done in raising a weight vertically through the height of the plane.

LABOURING TEN HOURS PER DAY.*

	Units of Work
Raising materials with a wheelbarrow on ramps	720
Throwing earth to the height of 5 ft.	470

LABOURING EIGHT HOURS PER DAY.

Raising his own body	4,250
Working with his arms and legs, as in rowing	4,000
Working the treadmill	3,900
Drawing or pushing horizontally	3,120
Turning a handle	2,600
Pushing and drawing alternately in a vertical direction	2,380

LABOURING SIX HOURS PER DAY.

Raising material with a pulley	1,560
„ „ the hands	1,470
„ „ upon the back, and returning empty	1,126

EXAMPLE : How many tons of rubbish would two men haul with a jack-roll from a sinking pit, whose depth is 15 yds., in 8 hours ?

By the table, we see that a man turning a handle would perform 2,600 units of work in a minute.

Then $2,600 \times 60 \times 8 \times 2 =$ work done, and to find the tons raised we must divide by the number of pounds in a ton multiplied by the depth in feet, thus—

$$\frac{2,600 \times 60 \times 8 \times 2}{2,240 \times 45} = 24.76 \text{ tons. } \textit{Answer.}$$

On this subject we give some information from the “Glossary of Terms used in the Coal Trade of Northumberland and Durham,” article “Barrow-man” :—

“The average day’s work of a barrow-man or trammer who, when putting alone, is a young man from seventeen to twenty or twenty-one years of age, is

* “The Colliery Manager’s Pocket-Book” (1871).

equal, on a level road laid with bridge rails, and with tubs having flanged wheels 10 in. diameter, to—

“ One empty tub = 3 cwt. pushed 8,280 yds.,		lb.
or 7057 tons pushed 1 mile, or . . .		8,346,240 pushed 1 ft.
“ One full tub = 10 cwt. pushed 8,280 yds.,		
or 23·523 tons pushed 1 mile, or . . .		27,820,800 „
“ Total day's work : 3·0580 tons pushed a		
distance of 1 mile, or		36,167,040 „

“ And, taking friction at $\frac{1}{8}$ part, the mean permanent force exercised by the barrow-man for 12 hours is equal to 556,416 lb. raised 1 ft. in 12 hours, or 773 lb. raised 1 ft. in 1 minute.”

A horse-power, according to Boulton and Watt—the recognised standard—is 33,000 units of work done in 1 minute.

According to practical results, a horse drawing a coach can travel 10 miles an hour for one hour and carry a load of 10 cwt. A dray horse can travel $2\frac{1}{2}$ miles an hour, or 16 miles per day, frequently drawing 2 tons, including the cart. Hence the power in the one case is as the square root of the speed in the other ; or the law of quantity of work done is as the square root of the velocity—the latter taking four times the weight of the former nearly double the distance. The traction, or force with which animals pull, decreases with the increase of speed. Tredgold exhibits their relations as below :—

Rate per Hour.	Traction.
2 miles	166 lb.
3 „	125 „
$3\frac{1}{2}$ „	104 „
4 „	83 „
$4\frac{1}{2}$ „	62 $\frac{1}{2}$ „
5 „	41 $\frac{2}{3}$ „

The amount of useful work performed by either man or horse in pushing or drawing a loaded truck depends very largely upon the road over which the weight has to be moved, and the consequent friction offered by the material and state of repair of the road.

The following table will show the loss thus incurred, and will illustrate the diminution of labour in proportion to the perfection of the road or railway :—

EXPERIMENTS SHOWING FRICTION ON VARIOUS ROADS.*

	Of the whole Weight.
Loose, sandy soil	Friction = $\frac{1}{8}$.
Turnpike road newly gravelled	„ = $\frac{1}{7}$.
Ordinary byeroad	„ = $\frac{2}{15}$.
Hard compact loam	„ = $\frac{1}{10}$.
Dry hard turf	„ = $\frac{1}{25}$.
Turnpike road with dirt	„ = $\frac{1}{15}$.
„ „ free from dirt	„ = $\frac{1}{25}$.

EXPERIMENTS SHOWING FRICTION ON VARIOUS TRAMWAYS AND RAILWAYS.†

	Of the whole Weight.
On colliery railways	Friction = $\frac{1}{40}$.
On underground tramways with 11½-in. wheels, with the road in good condition and round-top rails	„ = $\frac{1}{15}$.
On underground tramways with rails worn at the top or flat-top rails, and with the road in ordinary condition	„ = $\frac{1}{25}$.
On ordinary underground tramways with 7½-in. wheels	„ = $\frac{1}{25}$.

The friction of a railway tram is from 8 to 10 lb. per ton, or $\frac{1}{25}$ to $\frac{1}{20}$ of the whole weight. In the best constructed carriages it is perhaps as little as $\frac{1}{40}$ to $\frac{1}{50}$.

The above figures show the great importance and saving in labour to be effected by having tram-roads laid and maintained in the best possible manner. Underground, owing to the sharp curves, it is often difficult to maintain the road in good condition, but on the surface no such excuse is valid, and there is no reason why the surface tram-roads connecting the mine with the mill or shipping port should not be laid down in the first instance with as much care as to curves, gradients, and permanent way as a regular narrow-gauge road, designed for passenger traffic.

Men.—The approximate daily work which a man can perform on a level railway may be obtained on the basis that a man can move a waggon containing 12 cubic feet of earth, equal to 10 cwt., at a speed of 1½ mile per hour, returning with the empty waggon

* By Mr. Alexander Gordon.

† By Mr. Nicholas Wood.

at a speed of $3\frac{1}{4}$ miles per hour. Taking an average speed of $2\frac{1}{4}$ miles per hour, a man in a day of 10 hours could therefore move about 60 tons weight of earth a distance of 200 yards, being about ten times as much as could be done by a navvy with a wheelbarrow.

Horses.—Horses can be advantageously employed, both on the surface and underground tram-lines, and the amount of useful work they will do will depend upon the state of the roads, the construction of the trams, and the siding arrangement. The road intended for a watercourse need not have a fall of more than 1 in 250 to 200, but the inclination at which a horse will do the largest amount of work is when the resistance is the same in both directions, the fall being with the load, which may be something steeper. It is likewise in favour of horse-work to have the roads straight, to avoid sharp curves, and to have the gradient regular. With regard to the tram wheels, as the friction of them is in inverse proportion to the diameter, large wheels are preferable to small ones when height will admit of their use. With the roads and trams both good, and proper siding accommodation, and no delays at the end of the journeys, it may be calculated that a horse will do a fair amount of work, and this may be summed up as follows:—

On a level railway a horse can draw seven waggons loaded with earth, each containing about 20 cubic feet, equal to 7 tons weight, at an average speed of $2\frac{1}{2}$ miles per hour. A horse can thus move about 70 tons, a distance of one mile, by making ten trips with loaded waggons, and returning empty, as a day's work on a level railway, whereas on an ordinary road with a two-wheel cart a horse could not do more than one-tenth of the work in the same time.

TRAMWAY CONSTRUCTION:—*Wheels.*—The question as to whether the tram wheels should be fixed or loose upon their axles, is one upon which much might be written both for and against. Generally speaking, however, it may be said that loose wheels are better adapted to running on the tortuous roads underground where the curves are sharp, and on the other hand fixed wheels are to be preferred for work upon the surface roads, where the conditions more nearly resemble those of a railway.

Self-acting inclines, on which the loaded trucks descending haul up the empties, are in frequent use both on the surface and underground, and to these the following remarks apply.*

To find the gradient at which the full tubs on an incline will balance the empty ones—

$$\begin{array}{ll} \text{Let} & L = \text{Full load,} \\ & E = \text{Empty,} \\ & F = \text{Friction,} \\ & \text{and } x = \text{Gradient.} \\ \text{Then} & F \times \frac{L + E}{E - L} = x. \end{array}$$

We think, however, we are not far wrong in stating that inclines underground will not work under a gradient of 2 in. per yard, or 1 in 18.

The empty trams on an incline will draw out the rope from a stationary engine, when the fall is about 1 in 28; but not a less inclination, unless, indeed, the friction be reduced to a minimum.

The above remarks apply only to the case of *tramways*; on *railways*, the friction being, generally speaking, less than one-half, inclines will work at a less gradient. According to Mr. B. Thompson, eight laden chaldron waggons, descending a plane of $\frac{5}{8}$ in. per yard (1 in $57\frac{3}{8}$), will bring up eight empty ones at a good working speed. Six laden waggons require a fall of $\frac{3}{4}$ in. to the yard (1 in 48), and four laden waggons require $\frac{7}{8}$ in. to the yard (1 in $41\frac{1}{7}$).

Gauge.—The question as to the most suitable gauge for the tramways in and about a mine is usually decided by local conditions, such as the gauge in use at neighbouring mines, or the stock of the manufacturer who supplies the waggons, the weight of the mineral, etc. The narrowest gauge in successful use on a large scale is probably 1 ft. $11\frac{1}{2}$ in., the gauge of the Festiniog Railway, constructed for the purpose of conveying slates and passengers from Festiniog to the Port of Portmadoc. Locomotives are used for traction, and after leaving the main line the waggons are hauled up the self-acting inclines into the quarries. Tramways are laid with gauges of only 18 in., which may be taken as the minimum, the

* "Colliery Manager's Pocket-book."

maximum being a 36 in., or say a metre gauge, beyond which size the line comes under the category of a railway.

Rails.—The rails used are either those known as “bridge,” the single-headed flange rails, or the double-headed rail, which is rarely employed in mines as it involves the use of chairs. The bridge and flange rails are secured to wooden sleepers, placed about a yard apart by means of stout nails or “dogs.” The joints are made by simply nailing down the abutting ends on a somewhat broader sleeper, though, for permanent work with flange rails, fishplates should be used.

The weight of rail per yard depends upon that of the load to be carried, and the gauge. It is always advisable, however, to have a heavier rail than is absolutely necessary to carry the weight. For general mining purposes the weight per yard is usually from 14 to 16 lb.

The following table will give an approximate idea of the weight of rails, gauge of line, load, and cost per yard of railway all complete ready for laying, with steel flange rails, patent steel sleepers, fished joints, made up in five-yard lengths with sleepers three feet apart.

						Approximate Load per Axle.	Price per yard of Railway.
							s. d.
Rails 9 lb. per yard for 18-in. gauge tramway .						1000 lb.	. 2 4
„ 12 „	„	18 „	„	„	„	1500 „	. 2 9
„ 16 „	„	20 „	„	„	„	2 ton	. 3 5
„ 16 „	„	24 „	„	„	„	2 „	. 3 6
„ 24 „	„	30 „	„	„	„	4 „	. 4 11

For permanent light railways with passenger and goods traffic worked by locomotives, often laid as feeders to a main line system, and for the transport of the material to and from a group of mines or mining district, the metre gauge with rails weighing from 40 to 50 lb. per yard is now widely established.

Sleepers.—In countries where there is an abundance of wood this material is employed for sleepers, but of late years metallic sleepers made of sheet steel have come into general use. Messrs. J. and F. Howard, of Bedford, who are makers of portable railway plant for mining and other purposes, have adopted the form of

sleeper shown in figs. 305 and 306. The sleeper is made of plate steel corrugated and flanged in order to give the greatest strength

FIG. 05.—STEEL SLEEPER, KEY, AND RAIL.

with the least weight of material. The chairs for the rails are formed by pressure on the crown of the sleeper, none of the metal

FIG. 306.—PORTABLE RAILWAY, SHOWING JOINTING SLEEPERS.

being cut away, but, on the contrary, those parts of the chairs upon which the rails rest are increased in thickness and durability, and

as the chairs are made by special hydraulic machinery the exact gauge of the line is always maintained. The rail thus rests upon the whole width of the sleeper, giving great bearing surface. No bolts, dogs, or rivets are required, the only fastening being the simple metal key shown in the drawing, and this is serrated on one side to fit into the cheeks of the chair when driven home. For underground work a modified form of sleeper is used which can be threaded on to the rails and the keys thus dispensed with.

The method of laying the line is shown in fig. 306. The jointing sleepers are formed in the same manner as the single sleepers, except that two corrugations are rolled on one plate; the chairs or rail seats are pressed out of each corrugation in such a manner that the rail ends abut and are held in each seating respectively by its own serrated key. The keys are so arranged that either of them may be taken out without disturbing the others. This method of fastening and joining the lengths of rails, enables the laying down, and also the removing of the road to be effected with the greatest ease and despatch.

The corrugated form of sleeper allows the ballast to set down very firm under the sleeper, and the rail seats being below the crown of the sleeper, prevent any tendency of the sleeper to shift sideways on curves. For animal power lines this is the strongest form of sleeper, as the corrugation prevents any bending likely to be caused by the constant treading of the animals employed, and also gives a good foothold, thus preventing the slipping so frequent on flat-crowned sleepers.

The advantages of a portable line of rails of this form may be summed up as follows:—

Simplicity, strength, and durability.

Accuracy of gauge, which cannot vary, as the seats for the rails are formed by special machinery.

The gauge does not depend on the skill of the workman, and will be preserved as long as the line lasts.

No bolts, rivets, or spikes, with their many disadvantages, are required to fasten the rails to the sleepers.

A metal *safety key* fastens the rail to the steel sleeper, so that it cannot shake loose.

The rails may be laid down, removed, and relaid in the most expeditious manner, without skilled labour.

The rails and sleepers not being riveted together, stow into small space, whereby cost of freight is reduced to a minimum.

In order to prevent corrosion, the patent sleepers are coated with an anti-oxidation compound, while for handling and shipment there is no fear of any damage to the sleeper or alteration in shape, nor are there any projections to break off. They are shipped ready for laying, a great consideration where skilled labour is scarce.

The suitability of various lines depends largely upon the weight of the locomotive to be used, the traffic over the line, and the loads to be carried. The attention given to the laying and ballasting of the road has a great influence upon the resistance of the line to the load. The wear and tear upon the railway, as well as the rolling stock, increases considerably as the load approaches the maximum carrying power of the line, and although such a line is cheaper in first cost, it will be found far more expensive for subsequent maintenance and renewals than a heavier railway, the strength of which is well beyond the maximum loads and traffic it has to carry.

On lines of a semi-permanent character where locomotives are used, the employment of the jointing sleeper, so advantageous on a portable railway, becomes unnecessary. Hence it is usually preferred to lay such lines with the ordinary suspended fish joint, similar to that in general use upon main lines. The rigidity of the line is maintained, and the jointing sleeper is dispensed with.

For light locomotives suitable sleepers should be placed 3 ft. from centre to centre. For heavier traffic stronger sleepers are recommended to be placed 2 ft. 9 in. from centre to centre.

In the setting out of a light permanent line, too much care cannot be bestowed upon the preparation of the road, as this will be amply repaid by the saving in the subsequent cost of working the line. Before fixing upon the route to be followed, a rough survey is advisable, avoiding as far as possible heavy gradients and sharp curves. Careful attention to the ballasting of the sleepers will render the travelling easier and the working expenditure less,

while heavier loads can be carried. Sharp curves entail great wear and tear on the line and rolling stock.

For semi-portable lines less attention is paid to the laying and ballasting of the line, and therefore the same load cannot be carried on these as on well-ballasted, light permanent lines of the same weight.

For lines worked with locomotives either 1760 or 1920 steel sleepers are supplied for each mile of railway according to the work. For permanent light lines worked with locomotives, the steel sleepers should be spaced 2 ft. 9 in. from centre to centre, that is, 1920 sleepers to each mile of railway.

The rails are supplied in lengths up to 21 ft., and of various sections according to the nature of the traffic.

The usual gauges for these lines are as under :—

With Rails per yard.	Gauges.	With Sleepers.	Approximate average weight with sleepers, keys and fish-plates per mile.	Length of sleeper over and above the gauge.
14 lb.	$\left\{ \begin{array}{l} 20 \text{ in., } 24 \text{ in.,} \\ 500 \text{ mm., } 600 \text{ mm.,} \\ 30 \text{ in., } 36 \text{ in.,} \\ 750 \text{ mm., } 900 \text{ mm.} \end{array} \right\} \text{ metre}$	1760 No. 4	34 tons	12 in.
16 lb.	$\left\{ \begin{array}{l} 20 \text{ in., } 24 \text{ in.,} \\ 500 \text{ mm., } 600 \text{ mm.,} \\ 30 \text{ in., } 36 \text{ in.,} \\ 750 \text{ mm., } 900 \text{ mm.} \end{array} \right\} \text{ metre}$	1760 No. 4	37 tons	12 in.
18 lb.	$\left\{ \begin{array}{l} 24 \text{ in., } 30 \text{ in.,} \\ 600 \text{ mm., } 750 \text{ mm.,} \\ 36 \text{ in.,} \\ 900 \text{ mm.} \end{array} \right\} \text{ metre}$	1760 No. 4	41 tons	$\left\{ \begin{array}{l} 12 \text{ or } 18 \text{ in.,} \\ \text{according} \\ \text{to the} \\ \text{work.} \end{array} \right.$
22 lb.	$\left\{ \begin{array}{l} 24 \text{ in., } 30 \text{ in.,} \\ 600 \text{ mm., } 750 \text{ mm.,} \\ 36 \text{ in.,} \\ 900 \text{ mm.} \end{array} \right\} \text{ metre}$	1920 No. 2	53 tons	$\left\{ \begin{array}{l} 18 \text{ or } 24 \text{ in.,} \\ \text{according} \\ \text{to the} \\ \text{work.} \end{array} \right.$
26 lb.	$\left\{ \begin{array}{l} 30 \text{ in., } 36 \text{ in.,} \\ 750 \text{ mm., } 900 \text{ mm.} \end{array} \right\} \text{ metre}$	$\left\{ \begin{array}{l} 1920 \text{ No. 2} \\ 1920 \text{ No. 3} \end{array} \right.$	$\left\{ \begin{array}{l} 61 \text{ tons} \\ 64 \text{ tons} \end{array} \right.$	$\left\{ \begin{array}{l} 18 \text{ or } 24 \text{ in.,} \\ \text{according} \\ \text{to the} \\ \text{work.} \end{array} \right.$
40 lb.	$\left\{ \begin{array}{l} 36 \text{ in.,} \\ 900 \text{ mm.} \end{array} \right\} \text{ metre}$	1920 No. 7	105 tons	24 in.

Points and Crossings.—For shunting purposes underground, on the pit bank or in the mill, especially if the wheels run loose on their axles, it is customary to employ a square cast or wrought-iron plate upon which the tram waggon can be twisted in any direction. For permanent outside work, and also on the main roads underground, properly designed points and crossings, such as those shown in figs. 307 to 310 must be used.

Fig. 307 is a three-way, fig. 308 a right-hand, and fig. 309 a left-

FIG. 307.—THREE-WAY POINTS.

hand set of points and crossings, while fig. 310 shows the arrangement of a siding.

The sidings are formed, as shown in the illustration, by a set of points and crossings, either right or left hand, a section of curved line, and a number of sections of straight line.

Pass-bys in a straight line are made by a pair of right and left hand points and crossings, with two curve pieces and the desired length of line between. These pass-bys are necessary on lines of any considerable length, and especially where many waggons are in use.

For special curves, which must be shaped on the spot, an ordinary rail bender, called a "Jim Crow," is required.

The points are made with movable tongues or switches connected together by a cross bar. For locomotive-power lines the points are provided with levers and switch boxes ; but for animal

FIG. 308.—RIGHT-HAND POINTS.

power lines, levers, and switch boxes are not usually considered necessary. For locomotive traffic the points and crossings can be provided with a signal disc or lantern.

The single set either right hand or left hand may be so con

FIG. 309.—LEFT-HAND POINTS.

trived, that by taking a pair of rails from any part of the straight line, the points and crossings will take the place of the removed section of rails without cutting or fitting, and this removal can be quickly effected.

As a general rule, when setting out a line, it is better to arrange

for single sets of points as far as possible, for the wear and tear on two single sets of points will be found very much less than on one set of double points, and there is the further advantage of simplicity in laying down and keeping the line in order.

For the successful working of portable railways it is very important that the points and crossings should be accurately made, and so constructed that they cannot easily get out of form by the wear and tear of traffic.

The points and crossings are made of standard sizes with curves of 20, 25, and 30 ft. radius, and, where locomotives are used, they are made with curves of 100 ft. radius, or to any special radius required to suit the gauge of the rails and the wheel base of the

FIG. 310.—ARRANGEMENT FOR SIDING.

engines. For locomotives on the main line of tram the curves should not, as a rule, have a radius of less than 150 to 200 ft.

When the tram and load is too heavy to be turned on a plain plate some form of turntable becomes necessary. It should, however, be remembered, in laying down a plant, that wherever curves and points can be used instead of a turntable, the advantages of the curve are considerable, and, except in very confined positions, a curve can generally be adopted. A train of waggons will pass a curve in less time than a single truck can be turned on a table. There are, however, positions where turntables are indispensable.

TRAM WAGGONS.—The older forms of tram waggons for mining purposes were constructed chiefly of wood, which was rapidly

destroyed by the rough usage to which of necessity the trunks were subjected.

The type now commonly in use in South Africa, the Transvaal, and many other mining districts, is shown in fig. 311.

The tub is made of steel plate with one flanged end firmly rivetted in, the other end being formed by a flap door hinged at the top on a round bar, which is in one piece with the rivetted half-round top beading. This top beading is a solid welded ring,

FIG. 311.—TIPPING WAGGON.

and holds the body rigidly together. By this means the manifold advantages of a solid top beading are secured, whilst a simple hinged door is obtained. The lever catch fastening the door passes under the tub, and is worked from the rear of the waggon, and a through drawbar is provided.

The tub is mounted on an oak under-frame, the ends being shod with wrought iron and the wheels are placed close together and slightly to the rear of the waggon, thus ensuring an easy tip.

If desired the ends of the oak under-frames can be fitted with special buffers.

If required the wheels and axles are fitted up with a fiddle-frame, so that the hind pair of wheels do not leave the rails. The axles and wheels are of steel.

The usual sizes of these waggons are 10 cubic ft. and 16 cubic ft. capacity.

Tipping waggons are constructed in various forms to suit the purpose for which they are to be used, such as the single end tip, the double side tip, and the all-round tip waggon; the general construction is the same, but is so arranged that the load may be discharged as described.

The tip waggons are made with steel tubs, carried upon two pairs of wrought-iron trunnions. These trunnions are firmly rivetted through the end plate of the tub, which is strengthened by an additional inside and outside trunnion plate. The tub ends are flanged by hydraulic machinery, and are rivetted firmly to the sides, which are of one plate. A strong half-round welded ring is rivetted round the top of the tub, and holds it rigidly together. By this method of construction a very strong and durable tub is obtained. The under-frame is of channel steel, with steel bowed buffer ends, and steel angle stays across the under-frame; the draw gear is attached to a through stay; the axles are of steel and the wheels of chilled iron or cast steel. Waggons with round buffer ends are far superior for light railway work to those built with corner buffers, as the liability to derailment on curves is greatly lessened. The trunnions are placed at such a distance apart as to ensure steady running, thus dispensing with safety chains whilst still maintaining an easy tip. In some sizes of waggons four pairs of trunnions are employed to ensure a good tip.

The tubs which lift off the under-frame can be supplied with two stout rings to receive hooks from chains at the end of a winding rope. The body of the waggon, with its load of ore, can thus be wound up the shaft and dropped on to another frame at the surface; or it can be transported, with its load, by an aerial tram placed on a fresh framework at the end of its journey, thus avoiding the carriage of useless weight.

For mining purposes the double side-tipping waggon, shown in fig. 312, is largely used.

The special form of the steel tub admits of large capacity without great width, and allows the waggon to pass through narrow drives. It is also very suitable for work on the surface. By the use of four pairs of trunnions a large tipping angle is obtained, the material thus emptying freely.

The general construction of the waggon is similar to the other

FIG. 312.—DOUBLE SIDE-TIPPING MINING WAGGON.

forms of tip waggons. The under-frames are of channel steel and the trunnion supports of angle steel.

The drawbar passes throughout the length of the under-frame, forming a central stay.

The waggons are fitted with axle boxes, steel axles, and chilled iron or steel wheels.

The usual sizes of these waggons are 10 cubic ft. and 16 cubic ft. capacity on a gauge of 18 in. to 24 in.

For the purpose of controlling and ascertaining the daily output of the mine the waggons should be weighed, and their weight painted on the side.

Before entering the mill the loaded waggons should all be weighed, and the net weight of the ore entered in a book kept for that purpose. This weighing of the crude ore, taken in conjunction with the sampling under the rock breaker, will give the daily value of the ore treated, while the weight and assay of the concentrated ore will give that of the output of the mill.

The difference between the two will be the amount of loss in treatment, and to this little difference the manager cannot pay too much attention.

FIG. 313.—TRACTION ENGINE.

TRACTION ENGINES.—The use of the traction engine forms the last link in the chain of transport by road which commences with panniers on mule-back, is followed on by all sorts of wheeled vehicles drawn by bullock- or horse-power, and ends with these road locomotives, which, in many parts of our own country,—in Wales and Cornwall—and in different foreign countries, are employed to haul the produce of the mines and quarries to the nearest railway station or shipping port. Their use, however, implies the existence of a tolerably good hard road, with bridges and culverts sufficiently strong to carry their weight, and a highway-board not too exacting in the matter of rates. In England the

speed on turnpike roads or public highways is regulated by that of the man, who is required by law to be employed to walk a short distance (at least 20 yards), in front of the engine carrying a red flag, in order to warn the drivers of approaching vehicles. The latter can cause the engine to be stopped if their horses are restive, in which case the man with the flag helps to lead them by. It is astonishing, however, how quickly horses become accustomed to the engine when they meet it frequently on the same road as themselves.

The engines have considerable hill-climbing power, and can drive themselves up any hill that a horse and waggon could sur-

FIG. 314.—WAGGON FOR TRACTION ENGINE.

mount; but for practical purposes it may be laid down that gradients greater than 1 in 12 cannot be economically worked, and that up these the engine will haul a load equal to twice its own weight.

The most improved form of traction engine, as made by Messrs. Aveling and Porter, of Rochester, is shown in fig. 313, and the type of waggon manufactured by the same firm for use with these engines is shown in fig. 314.

The engine boiler and fire-box are made of the best quality steel or Yorkshire-iron plates, and the boiler itself is tested by hydraulic pressure to 250 lb. per square inch.

Up to within recent years it was the universal practice to mount the principal working parts of these engines on cast- or wrought-iron brackets bolted to the boiler, and the strain thrown on the boiler by the unequal working of the crank shaft, countershaft, and driving axle always manifested itself sooner or later in leakage at the numerous bolt holes and in corresponding corrosion of the boiler plates. In order to obviate this difficulty Messrs. Aveling and Porter patented the arrangement of brackets since fitted to all their engines, which entirely overcame these evils and at the same time provides more stable and convenient bearings than under the usual system of construction. By prolonging the side plates of the fire-box upwards, perfect brackets are formed without the necessity of bolting them to the boiler; and these brackets are so shaped as to carry the bearings of the crank shaft, countershaft, and driving axle, and, therefore, to effectually relieve the boiler from their strain.

Another improvement has also been effected. Hitherto the gearing of road locomotives has been placed outside the crank and countershaft brackets; but by the new arrangement of gearing the wheels and pinions are fixed to their respective shafts between (not outside) the bearings, and the driving-wheels as well as flywheel are brought up close to the side-plate brackets. The engine is stronger, narrower, more compact in consequence, and its wear and tear most substantially reduced. The flywheel is fixed close to the crank-shaft bearings. The engine is geared for two speeds and the pinions for these two speeds are keyed fast upon the crank-shaft instead of sliding upon feathers. The intermediate shaft is fixed and serves as a stay to the side plates, and the sliding sleeve which carries the spur-wheel and the fast- and low-speed pinions, revolves on it. The axle, crank-shaft and counter-shafts are of steel. The gearing is all of the best crucible steel, and the teeth are shrouded.

The driving wheels are of large diameter and width, and are fitted with compensatory motion for turning sharp curves without disconnecting either wheel. The engine is steered from the foot-plate by means of the hand-wheel shown in the illustration.

Each engine is supplied with water elevator and 26 ft. of india-rubber hose, steam pressure-gauge, and extra safety-valve, a

The prices of traction engines and waggons vary greatly with the fluctuations in the price of metal, so that the following list of these machines, as made by Messrs. Aveling and Porter, of Rochester, must be taken as approximative only :—

	To carry	4 tons.	6 tons.
		£	£
Price with wrought-iron wheels and spring drawbar ...		60	70
Springs		10	10
Friction brake		3	3

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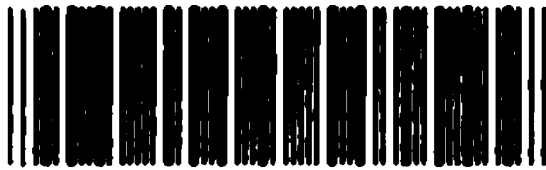
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